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SEISMICITY OF THE EARTH

BY

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AND

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INTRODUCTION

This paper is intended: (1) to give an account of the relative seismicity of various parts of the earth during the limited period for which accurate information is available, and (2) to identify and discuss the geographical and geological relationships of the principal zones and areas of seismic activity.

Maps purporting to show the distribution of earthquake epicenters have usually been based either on historical data or on the results of instrumental seismology, sometimes on both. Such maps, unless studied with critical attention, are likely to give a distorted impression of the facts. Historical macroseismic data are in general available only for land areas, and are much influenced by the present and past state of culture in the districts affected. Instrumental determinations require much careful sifting, for reasons which will become thoroughly apparent as the discussion proceeds. Many recent maps have been based on the epicenters published in the International Seismological Summary (Turner, *et al.*, 1923–1940) and similar compilations of earlier date, without any attempt to discriminate with reference to the accuracy of the determination, the magnitude of the shock, and in most cases even the focal depth. Further confusion is created by alternative epicenters suggested for poorly recorded shocks. Thus, for the earthquake of September 19, 1926, at 20^h,[1] the Summary gives the following four alternatives: 42° S. 130° E., 72° N. 2.8° W., 47° N. 10° E., 59° N. 65° E. Probably none of these is correct; the shock appears to be a deep-focus earthquake in the South Pacific. Nevertheless, these four epicenters appear as separate entries in the catalogues based on the Summary, and have appeared separately on maps. Instances of this kind are rather frequent, especially when only two alternatives are given.

There is no doubt that the International Summary is the proper basis for all investigations of this kind, including the present paper, which could hardly have been undertaken without it. The existence of inaccuracies in the Summary is no reflection on its very careful compilers but is due to a variety of causes, among which are: use in earlier years of travel time data which later research has shown to be in need of revision,—such as was adopted in the Summary for 1930 and following years; errors of inter-

[1] Times of shocks given in this paper regularly are Greenwich mean civil time (0^h to 24^h beginning at midnight) of occurrence at the seismic origin. The dates correspond to these, and may be one day earlier or one day later than the date according to local time in the country of origin. In a few cases, where this difference is likely to cause confusion, the local date has also been given.

pretation, clerical errors, and others at the reporting stations; the occurrence of small and imperfectly recorded shocks; and occasional confusion between deep and shallow shocks, with resulting errors in location.

Inferences as to the distribution of earthquakes often have been drawn from maps based on epicenters in the Summary without regard to the magnitude of the individual shocks. This results in apparent concentration of seismic activity in the vicinity of good stations. Such procedure is particularly misleading in the European area, where there are many first-class stations, so that comparatively small shocks in Europe find their way into the list of located shocks, while large shocks in remote regions may not be located even approximately. Location and listing is particularly incomplete for the southern hemisphere, especially in earlier years.

In the present paper an attempt has been made to eliminate these various sources of error.

MATERIALS USED

It is necessary first to distinguish deep-focus from normal earthquakes. The major part of this task has already been accomplished in two previous papers (Gutenberg and Richter, 1938; 1939). Additional results are given in the next section.

Normal shocks used have been classified by magnitude, in the sense defined by Richter (1935) for the California region and extended by Gutenberg and Richter (1936) to apply in general. The magnitude scale number is intended to be logarithmic in the maximum amplitude of earth motion at a fixed distance. The smallest shocks recorded (only on sensitive instruments at a distance of a few kilometers) are of magnitude 0; shocks of magnitude 3 are usually felt; shocks of magnitude 4½ are capable of causing slight damage; major earthquakes range from magnitude 7 to magnitude 8½. Increase in the magnitude by half a unit corresponds to multiplication of the energy released by a factor 10, so that there is a ratio of about 10^{17} between the energies released in the largest and the smallest earthquakes.

Magnitudes were originally derived for a limited number of shocks from the seismographic amplitudes reported in the individual station bulletins (Gutenberg and Richter, 1934, p. 118); but on investigation it proved practicable to estimate magnitudes for the purpose of this paper, from the distances out to which the direct waves were recorded, as entered in the International Summary. Five arbitrary classes were set up, which were later identified with the corresponding ranges of the magnitude scale as follows:

Class	*a*	*b*	*c*	*d*	*e*
Magnitude	7.8–8.5	7–7.7	6–7	5.3–6	<5.3

Shocks of classes *a* and *b* are recorded at all stations; class *c* is well recorded up to 90°, class *d* up to about 45°, and class *e* in general not beyond 10°. This classification has been adhered to in mapping and in most of the tabulation. Some shocks assigned to class *b* were later found to have magnitudes slightly below 7.

In making use of the International Seismological Summary, all shocks from January 1, 1931 to March 31, 1934 have been examined critically. For this period most of the epicenters given in the Summary can be accepted as accurate within 1 degree of arc. A small number of the Summary epicenters, listed as Table 3, have been altered slightly. Shocks of class *e* have been rejected, as well as imperfectly recorded shocks, for which it was considered that the epicenters might be in error by several degrees. These latter shocks are usually qualified as very doubtful in the Summary.

Numerous shocks in areas of special interest have been selected from the International Summary for 1920–1930 inclusive. Most of the epicenters in this period call for significant revision, which has been carried out with much care. The method used has been described elsewhere (Gutenberg and Richter, 1937). The results will be found in Tables 6–20 accompanying the discussion of the seismicity of specific regions.

The International Summary has also served as a basis for another tabulation of statistical importance (Table 4). This list contains all shocks of magnitude 7 to 7.7 from January 1, 1926 to March 31, 1934. For 1926–1930 magnitudes were determined by Richter (1936) from amplitudes of earth motion as reported in various station bulletins. All origin times, epicenters and magnitudes have been carefully revised. Note that 13 larger shocks occurring in these years are included in Table 5. The following shocks mapped as of class *b* have magnitudes slightly below 7:

1931, Jan. 2	9^h	19.2° N.	107.0° W.	1931, Feb. 27	9^h	2.3° N.	127.2° E.
1931, March 19	6	18.0° N.	120.4° E.	1931, April 6	6	7.0° S.	155.0° E.
1932, Jan. 24	3	16.9° S.	168.3° E.	1932, Feb. 16	13	15° S.	180°
1932, Nov. 2	11	22.2° S.	112.2° W.	1933, March 17	19	6.5° N.	127.0° E.
1933, May 16	1	7° N.	96½° E.	1933, July 9	12	44.7° N.	150.2° E.
1933, Sept. 25	18	38.3° N.	86.8° E.	1933, Oct. 2	15	2.1° S.	81.2° W.
1933, Nov. 22	12	5.7° S.	151.8° E.	1933, Dec. 12	14	4.3° S.	153.0° E.

A previous list of shocks of magnitude 7¾ to 8½ (Gutenberg and Richter, 1936) has served as a basis for further investigation. It is believed that Table 5 contains all very large shallow earthquakes from 1904 to 1940 inclusive. Epicenters and origin times have been revised, more recent shocks have been added, and a number of shocks which proved on investigation to have deep focus have been dropped.

At present the International Summary is available only to March 31, 1934. This renders the investigation of later shocks comparatively laborious, and in a sense premature, as the data of many stations are not

generally available until printed in the Summary. However, for shocks in areas where additional epicenters are important for the geographical survey collated data from individual station bulletins have been used to determine origin times and epicenters. These determinations must be considered only as preliminary and subject to revision in the light of more complete data. The results will be found in the regional tabulations (Tables 6–20). In this work the bulletins of the central office of the International Seismological Association, the U. S. Coast and Geodetic Survey, the Jesuit Seismological Association, and other publications giving collated data and determinations of epicenters have been of great aid.

Finally, in the geographical discussion, a limited use has been made of macroseismic and historical data. Sieberg (1932a) has been consulted throughout. Isobaths on the regional maps and terminology of oceanographic features are based on Vaughan, *et al.* (1940).

DEEP-FOCUS EARTHQUAKES

This section revises and extends the results reported by Gutenberg and Richter in two previous papers (1938; 1939), to which the reader is referred for sources of the material used and for discussion of methods. In addition, recent deep shocks in the Japanese area have been checked against a list by Wadati (1939) for the years 1934–1938.

The following corrections apply to our earlier papers:

Shock No. 105, 1933 October 27, not October 17; No. S 10, origin time 04:55:17; not 04:55:32.

Shock 218a of the 1939 paper is identical with No. 218 of the 1938 paper.

Shock S 31, 1931 Feb. 23, should be deleted. It is probably a very deep shock near 50° North 150° East close to No. 221.

New determinations of deep-focus earthquakes are given in Tables 1 and 2. All epicenters of deep-focus shocks now known to the authors are plotted in Figure 1.[2] They are also plotted, together with normal shocks, on the regional maps (Figs. 3–14).

The general characteristics of the distribution of deep shocks are as described in earlier papers. A few individual shocks call for special comment.

No. 3 p is in a new location near Barbados.

No. 81 M is the first shock with depth in excess of 300 kilometers to be located in the New Hebrides area.

Nos. 133 g and 133 i constitute an important southern extension of the line of intermediate shocks on Luzon.

[2] Maps used in this paper were drafted by Mr. John M. Nordquist. The world maps, Figures 1 and 2, are of his own design. The purpose was to construct a map which would present all the principal seismic areas and belts without excessive distortion or interruption. These world maps are not on any projection in the restricted sense; the meridians are drawn as circles, and divided proportionately into arcs through the ends of which the parallels are drawn.

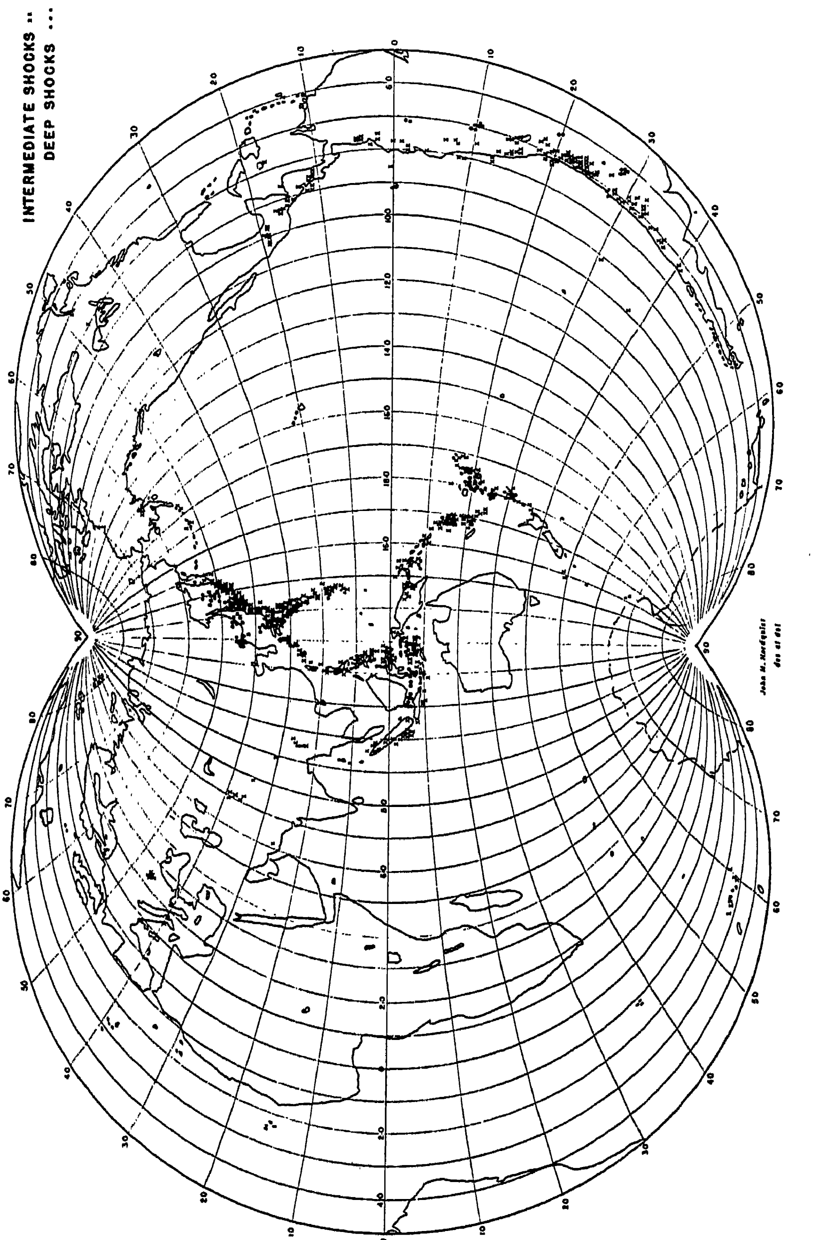

FIGURE 1.—*World map of deep-focus earthquakes*

TABLE 1.—*Data for deep-focus earthquakes*

First three capital letters refer, in order, to quality of determination of epicenter, origin time, and depth—(A) very accurate; (B) good; (C) fair; (D) poor. Small letter refers to comparison with International Seismological Summary (I.S.S.)—(a) at least approximate agreement with the Summary as to epicenter and depth; (b) I.S.S. gives shock as normal, with epicenter within 4°; (c) I.S.S. gives shock as normal, epicenter more than 4° distant; (d) I.S.S. gives the shock significantly deeper, epicenter in the same area; (h) I.S.S. not available; (k) Wadati gives approximately the same epicenter and depth; (n) Berlage gives approximately same epicenter and depth.

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
			MEXICO, CENTRAL AMERICAN, CARIBBEAN REGION			
0 b	1933, Oct. 10	13:34:52	19 N.	102 W.	110	BBBb
0 e	1928, Feb. 10	04:38:35	19 N.	97½ W.	100	BCBb
0 h	1939, May 23	02:49:43	18 N.	101 W.	90	BCBh
1 c	1932, May 22	22:40:02	14¼ N.	90 W.	80	BCBb
1 m	1934, Feb. 24	05:33:30	12¾ N.	86¾ W.	200	ABBa
3 c	1931, March 7	00:41:56	11½ N.	85½ W.	80	ACBb
3 e	1931, Dec. 20	14:59:42	11 N.	84½ W.	280	BCCa
3 m	1933, July 21	07:29:05	19 N.	68½ W.	100	BCCb
3 p	1940, July 6	03:40:24	13½ N.	60 W.	160	CCBh
			SOUTH AMERICA, INTERMEDIATE SHOCKS			
8 o	1926, March 7	20:33:38	5 S.	76½ W.	150	CCCb
8 p	1933, Oct. 1	02:40:42	7 S.	75¼ W.	120	AAAb
9 b	1937, June 21	15:13:04	8½ S.	80 W.	60	ABAh
9 d	1931, July 11	05:56:13	8½ S.	74½ W.	120	ABCb
9 r	1933, Aug. 6	02:54:52	11 S.	75½ W.	100	BCCb
10 r	1937, Oct. 15	03:41:15	13½ S.	77 W.	90	CCAh
11 b	1933, Aug. 9	23:02:45	15½ S.	68½ W.	170	BBBa
11 c	1940, Dec. 22	18:59:46	15½ S.	68½ W.	230	BBAh
11 t	1933, July 31	15:23:07	15½ S.	75½ W.	80	BBBb
11 w	1933, July 23	04:13:11	15¾ S.	75¼ W.	80	ABBb
12 s	1939, May 19	18:25:35	18 S.	69 W.	100	BCAh
13 d	1932, May 30	00:22:45	19 S.	69 W.	160	BBBb
13 f	1938, April 17	14:39:38	19 S.	69½ W.	60	BBBh
13 m	1933, Sept. 14	07:59:24	19 S.	70½ W.	100	BCBb
13 t	1932, June 18	00:13:39	20 S.	71 W.	70	BCBb
13 v	1931, May 28	03:15:04	20½ S.	70½ W.	120	CCBc[1]
15 d	1939, July 4	18:26:12	21 S.	66 W.	290	BBAh
16 c	1939, May 13	00:43:35	22 S.	66 W.	210	CCCh
16 e	1933, Nov. 3	04:14:43	22 S.	70½ W.	70	CCBb
16 g	1933, Oct. 10	03:34:12	22½ S.	69½ W.	110	BBBb
16 x	1932, Feb. 27	08:49:40	22½ S.	70 W.	120	BCBb
16 y	1937, Sept. 24	19:09:52	22½ S.	70 W.	130	BCBh
18 d	1933, Oct. 12	07:12:50	23 S.	69½ W.	100	BCBc
18 p	1934, March 24	22:52:46	23 S.	66 W.	270	BCCb

[1] Pasadena has P at 3:26:11, pP − P = 30 seconds, sP − P = 46 seconds.

TABLE 1.—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
South America, Intermediate Shocks						
19 d	1938, April 24	14:10:58	23½ S.	66 W.	180	BCCh
23 e	1936, July 13	11:12:15	24½ S.	70 W.	60	ABAh
23 g	1932, April 26	07:54:48	25 S.	69½ W.	70	ABBb
23 h	1937, Oct. 12	12:50:55	25 S.	68½ W.	110	ABAh
23 k	1931, April 3	05:19:06	27 S.	65 W.	180	ABBb
23 l	1932, June 9	06:30:43	27½ S.	70½ W.	80	BCBb
23 n	1934, March 31	03:13:00	28½ S.	72 W.	60	BCAb
23 P	1939, Jan. 18	01:44:18	29½ S.	71 W.	70	BBAh
23 q	1938, Jan. 9	20:26:00	30½ S.	69 W.	120	CCBh
23 Q	1938, June 23	01:03:58	30½ S.	70 W.	70	CBAh
23 t	1933, Dec. 21	04:31:55	31 S.	69 W.	120	BBBb
24 b	1931, Aug. 17	05:05:25	32½ S.	69½ W.	120	BCBb
24 p	1937, Oct. 27	00:21:20	34½ S.	71 W.	110	BCAh
25 m	1937, Dec. 24	03:23:38	37 S.	72 W.	70	BCBh
South America, Very Deep Shocks						
36 h	1940, Sept. 23	07:15:10	23 S.	64 W.	550	BBBh
36 p	1939, Jan. 24	19:48:53	26½ S.	63 W.	580	BBAh
New Zealand						
41 e	1931, Sept. 21	13:34:25	37½ S.	178 E.	80	BCBb
41 g	1939, May 14	18:12:24	36½ S.	179 E.	80	BCBh
Kermadec-Samoa Region, Intermediate Shocks						
41 h	1933, May 21	08:13:42	35 S.	180	100	CCCb
41 o	1933, Nov. 7	12:08:17	30 S.	177 W.	80	CCBb
41 p	1932, Oct. 20	17:36:43	30 S.	179 W.	70	CCBb
41 t	1933, June 11	13:09:12	22 S.	176 W.	80	CCBb
41 w	1934, Feb. 9	22:32:13	20½ S.	176½ W.	230	BCBa
42 a	1932, June 16	23:13:05	20 S.	176 W.	200	CCBc
44 i	1939, Oct. 30	13:12:36	16 S.	174 W.	150	BCAh
44 o	1939, June 8	20:46:53	15½ S.	174 W.	100	AAAh
Kermadec-Fiji Region, Very Deep Shocks						
50 d	1931, May 15	07:41:58	29 S.	180	500	CCCc
51 a	1940, Aug. 1	12:39:38	26 S.	180	500	BBAh
54 m	1939, May 21	20:21:53	22½ S.	179 W.	600	BCAh
55 a	1939, July 5	22:41:04	22 S.	180	650	CBBh
55 c	1939, July 20	02:23:00	22 S.	179½ W.	650	CCCh
58 d	1939, Nov. 17	18:39:30	21½ S.	178 W.	600	BBBh
59 m	1934, Jan. 18	03:21:05	21 S.	179 W.	580	CCCa

TABLE 1.—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
LOYALTY ISLANDS TO NEW GUINEA						
67 g	1931, Oct. 23	11:45:29	20 S.	170 E.	80	BCBb
67 n	1933, July 14	01:38:14	20½ S.	169½ E.	110	CDDd[2]
67 o	1933, Dec. 1	10:26:26	20½ S.	169 E.	140	BCBd
67 r	1939, April 5	16:42:40	19½ S.	168 E.	70	AAAh
67 t	1939, Aug. 27	11:18:00	19 S.	170 E.	280	CCCh
72 d	1932, July 9	12:56:10	14½ S.	167½ E.	120	ABBb
72 p	1933, July 30	17:15:31	15 S.	167 E.	160	CCBa
75 d	1940, Feb. 20	02:18:20	13½ S.	167 E.	200	AAAh
75 m	1933, Sept. 9	21:20:00	13 S.	166½ E.	130	ABBa
76 b	1933, Feb. 19	08:34:39	11 S.	163 E.	60	BCAb
76 g	1932, Oct. 17	13:25:31	7½ S.	157 E.	100	BCBb
76 n	1932, March 8	03:11:09	6 S.	154 E.	70	BCBb
76 N	1934, Feb. 27	21:29:35	6 S.	154 E.	180	ABAb
76 o	1932, July 14	08:53:28	3½ S.	154 E.	150	BCBb[3]
76 t	1932, April 12	23:52:40	4 S.	152 E.	100	BCBb
78 a	1939, Jan. 30	23:50:24	5½ S.	147 E.	200	BCBh
79 c	1931, June 17	17:02:00	6½ S.	146½ E.	140	BBBb
79 p	1933, June 4	13:40:17	5 S.	146 E.	120	BBBb
NEW HEBRIDES, DEEP SHOCKS						
81 M	1938, Nov. 18	14:12:35	13 S.	168 E.	360	BCBh
SUNDA ISLANDS, INTERMEDIATE SHOCKS						
86 t	1933, May 21	11:51:28	3½ S.	130½ E.	120	CCCb
92 h	1931, June 4	09:50:18	6½ S.	129 E.	150	BCCb
96 d	1931, April 2	12:22:56	6 S.	126½ E.	130	CCCb
97 m	1932, May 17	12:56:30	8½ S.	115 E.	80	BCBb
97 g	1931, April 24	05:47:00	10 S.	112 E.	100	CCCb
99 b	1933, July 13	14:23:25	7¾ S.	106½ E.	70	BBBb
99 c	1931, Nov. 23	13:35:47	5 S.	106 E.	140	BCAb[4]
102 a	1931, Jan. 20	15:26:32	4 N.	99 E.	150	BCCb
JAVA SEA AND FLORES SEA, DEEP SHOCKS						
109 d	1933, Aug. 25	09:26:05	6 S.	121 E.	720	CCCen
CELEBES AND MINDANAO, SHOCKS WITH DEPTHS BETWEEN 100 KM. AND 400 KM.						
118 d	1939, Dec. 21	21:00:40	0	123 E.	150	ABCh
118 f	1940, June 22	11:36:46	0	122½ E.	200	BBCh
118 g	1932, May 4	05:05:08	½ N.	122 E.	200	BCCb
119 d	1932, May 12	06:08:05	¼ N.	126 E.	170	BBBb
120 m	1939, June 13	20:39:55	¾ N.	125¾ E.	150	BBChn

[2] May be two shocks about 30 seconds apart with later origin time and larger depth, but in same region.
[3] Pasadena has pP 39 seconds and sP 52 seconds after P.
[4] Pasadena has P′ at 13:54:46 and pP′ 37 seconds later.

TABLE 1.—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
CELEBES AND MINDANAO, SHOCKS WITH DEPTHS BETWEEN 100 KM. AND 400 KM. —*Continued*						
125 d	1932, June 6	06:26:21	2 N.	122½ E.	280	CCCa
127 d	1932, July 9	20:23:54	5½ N.	126½ E.	120	BCBb
127 m	1932, June 10	20:21:20	5½ N.	127 E.	80	ABBb
128 d	1933, Sept. 7	17:53:38	6½ N.	126 E.	150	BCCb
128 g	1933, Sept. 28	00:27:58	7 N.	127 E.	100	CCCb
128 m	1932, June 8	14:54:38	8 N.	126 E.	100	BBBb
CELEBES TO MINDANAO, VERY DEEP SHOCKS						
131 h	1940, June 18	13:52:33	5½ N.	123½ E.	570	BBBh
132 b	1940, Sept. 22	22:51:56	8 N.	124 E.	680	BBBh
132 p	1941, Feb. 4	14:03:12	9 N.	124 E.	600	BBBh
LUZON TO KIUSHIU						
133 g	1933, Sept. 20	23:33:40	13 N.	121 E.	100	BBBb
133 i	1932, July 18	05:02:05	14 N.	120 E.	100	BCCb
133 k	1940, March 28	15:48:52	14½ N.	120 E.	200	ABAh
135 x	1932, June 14	05:59:38	18½ N.	120¾ E.	80	ABBb
136 g	1932, Oct. 9	12:49:49	23½ N.	122½ E.	130	BBCb
136 k	1933, Feb. 19	04:26:11	25 N.	123 E.	120	ABCb
138 p	1911, June 15	14:26:00	29 N.	129 E.	160	BCCh
MARIANNE ISLANDS-JAPAN-KAMCHATKA, INTERMEDIATE SHOCKS						
141 p	1931, Nov. 3	02:35:55	17 N.	147 E.	100	CCCb
141 x	1933, Nov. 7	06:39:58	18 N.	146 E.	70	CCBb
142 d	1930, Jan. 26	12:20:30	18½ N.	146½ E.	190	BCBb[5]
143 m	1932, Jan. 5	11:22:25	20 N.	148 E.	130	CCCb
144 t	1931, July 2	03:38:50	24 N.	142½ E.	120	BCCb
147 d	1923, Sept. 17	03:39:32	31 N.	140 E.	150	CCCb
147 m	1926, Sept. 26	01:00:39	32 N.	140 E.	200	CCCb
147 w	1933, Nov. 19	01:33:39	32½ N.	139 E.	230	AABak
148 d	1938, Jan. 11	15:12:00	33 N.	135½ E.	70	ABBh
148 m	1933, Sept. 15	13:53:45	33 N.	141¼ E.	120	AABa
150 g	1933, Sept. 6	14:05:20	34½ N.	137¾ E.	280	AABak
150 n	1934, Feb. 1	00:15:59	35¼ N.	139¼ E.	90	AAAhk
151 q	1931, May 25	06:48:55	38½ N.	141 E.	100	AABb
151 u	1933, July 20	23:14:05	38½ N.	144½ E.	100	AAAa
153 d	1934, Oct. 29	17:23:04	42 N.	141 E.	100	BCBhk
153 m	1931, Jan. 6	03:22:46	42½ N.	142¾ E.	100	AABbk
156 g	1931, Jan. 21	08:58:04	43¼ N.	146 E.	120	ABBbk
158 k	1933, Aug. 28	08:47:42	44 N.	147½ E.	130	BCBb
161 d	1938, Aug. 17	01:45:35	45 N.	148 E.	100	BCChk
162 d	1930, Nov. 12	20:04:46	46 N.	148 E.	150	BBBhk

[5] Pasadena has iP at 12:32:43 and pP 48 seconds later.

TABLE 1—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
MARIANNE ISLANDS-JAPAN-KAMCHATKA, INTERMEDIATE SHOCKS—*Continued*						
162 h	1933, Feb. 3	22:11:50	46 N.	151½ E.	70	ABAb
163 m	1932, April 26	13:31:39	47½ N.	154 E.	150	CCCc[6]
168 g	1939, Aug. 1	15:55:59	50½ N.	156 E.	140	BBAh
170 b	1932, Aug. 4	06:37:27	53 N.	160 E.	100	CBBb[7]
ALEUTIAN ISLANDS-ALASKA, INTERMEDIATE SHOCKS						
170 e	1933, Sept. 24	15:19:41	51¾ N.	177 W.	70	AAAb
170 k	1931, Dec. 24	03:40:40	60 N.	152 W.	100	BBAb[8]
MARIANNE ISLANDS-MANCHURIA-KAMCHATKA, DEEP SHOCKS						
174 a	1923, June 29	10:47:38	27 N.	140 E.	400	CCCah
174 b	1923, June 29	10:53:20	27 N.	140 E.	400	CCCah
174 c	1940, March 9	10:47:04	27 N.	140 E.	500	BCAh
181 k	1933, July 11	08:28:07	29 N.	139 E.	400	CCCa
181 p	1933, July 31	02:56:20	29 N.	141 E.	400	CCCb
185 a	1930, Jan. 11	21:21:00	30 N.	139 E.	500	CCCb[9]
185 d	1932, Oct. 6	05:00:53	30 N.	138 E.	500	CCCb[10]
187 a	1927, June 18	02:26:23	32 N.	139 E.	400	CCCa
188 a	1927, Aug. 20	22:12:36	33 N.	138 E.	350	CCCbk
191 d	1933, Sept. 20	03:56:35	34 N.	136½ E.	380	AABa
197 m	1935, Oct. 15	14:35:09	37½ N.	135 E.	330	AABhk
200 a	1933, July 24	08:37:57	42½ N.	131 E.	550	AAAa
206 p	1940, July 10	05:49:55	44 N.	131 E.	580	BBAh
206 x	1933, May 22	15:29:08	43 N.	136½ E.	350	BCCb
223 n	1940, May 19	15:17:55	51 N.	149 E.	580	ABAh
223 p	1932, Nov. 6	12:47:53	51 N.	150 E.	520	BCCc[11]
224 p	1931, Aug. 2	23:29:45	51½ N.	151½ E.	400	BCCc[12]
HIMALAYA, INTERMEDIATE SHOCK						
229 p	1937, Nov. 15	21:37:34	35 N.	78 E.	100	ACCh

[6] Pasadena P at 05:41:52, pP or sP about 48 seconds later.

[7] At Sverdlovsk, P is reported as of a separate preceding shock; the following impulse, 23 seconds later, is reported as P of this shock, but is probably pP. Frunse and Yalta report the true P, whereas six other stations in azimuths 290° to 343° at distances over 59° apparently have records beginning with pP, about 20 seconds after P. Pasadena has sharp P and much smaller pP 21 seconds later. All stations in azimuths 0–270° report P.

[8] Pasadena has P at 03:47:17, pP 21 seconds later.

[9] Added: data reported by Almata, Andijan, Samarkand.

[10] Added: P at Pasadena 05:12:33, at Tinemaha 05:12:25.

[11] Pasadena has P at 12:57:47 and pP $1^m 45^s$ later.

[12] I.S.S. gives one epicenter for the near-by stations and another for the distant stations, both normal. Pasadena has pP − P of 82 seconds; no surface waves.

TABLE 1—*Concluded*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
			HINDU KUSH			
231 d	1909, July 7	21:37:50	36½ N.	70½ E.	230	CCCh
243 p	1931, Jan. 7	03:49:42	36½ N.	71 E.	200	CCCb
245 m	1931, Sept. 14	03:32:16	36½ N.	70½ E.	220	ABBb
246 d	1932, Feb. 9	02:19:44	36½ N.	70½ E.	220	CCCb
246 h	1932, April 30	10:52:41	36¾ N.	70½ E.	250	ABBb
247 m	1933, May 21	17:53:43	36½ N.	70½ E.	220	CCCb
247 t	1933, July 25	13:38:23	39 N.	72 E.	250	BCCb
250 k	1939, Nov. 21	11:01:50	36½ N.	70½ E.	220	AAAh
250 m	1940, Sept. 21	13:49:03	36½ N.	70½ E.	230	BBBh
			SOUTHEASTERN EUROPE			
251 m	1941, Jan. 20	03:37:07	35 N.	34 E.	100	BBBh
252 q	1934, March 29	20:06:51	45¾ N.	26½ E.	150	ABBh
252 r	1939, Sept. 5	06:02:02	45¾ N.	26½ E.	150	BBBh
252 s	1940, Oct. 22	06:37:00	45¾ N.	26½ E.	150	AAAh
252 t	1940, Nov. 10	01:39:10	45¾ N.	26½ E.	150	AAAh
			SOUTH ATLANTIC			
254 d	1937, Sept. 8	00:40:01	57 S.	27 W.	130	BBBh
256 a	1932, Feb. 23	00:13:54	60 S.	12½ W.	150	BCCb

No. 138 p was originally in the list of great shocks, presumed to be at normal depth. A note by Mr. H. O. Wood in the Bulletin of the Berkeley station for 1911, referring to peculiarities in the seismogram, suggested that the shock was deep. Inspection of the original Berkeley seismograms, kindly lent by Professor Byerly, showed very small surface waves and a pP-P interval of 40 seconds.

Intermediate shocks in the Hindu Kush region have continued, the most recent large shock of the series having occurred on September 21, 1940. The total number of known shocks from practically the same epicenter and depth in the last 20 years is at least 40.

No. 251 m was destructive on Cyprus.

No. 252 t was very destructive in Roumania.

No. 256 a is a new epicenter in the South Atlantic, lying well to the east of the active structure loop of the southern Antilles.

No. S 14 i, north of the Fiji Islands, falls in an otherwise large gap in the line of epicenters. Owing to the early date of this shock, the location and determination of depth are not precise.

No. S 10 m, on the south island of New Zealand, is well established from both macroseismic and microseismic data. The location on that side of the island remote from the Pacific is important.

No. S 5 m is reasonably well located, about midway between the Galápagos Islands and the coast of South America. It is most probably at intermediate depth, although the data for determining this depth are not as satisfactory as those for the epicenter;

however, any depth from normal depth to 150 km. is consistent with the observations. The shock is not small, and the epicenter is an important one whether the focus is deep or not.

In classifying shocks by depth, we have retained our previous grouping: shallow shocks, with depths definitely less than 60 km.; intermediate shocks, with depths from 60 to 300 km.; deep shocks, at depths greater than 300 km. below the surface. The latter limit appears to be fairly definite. However, it is often difficult to distinguish intermediate from shallow shocks; this is partly due to difficulty in fixing the depth precisely, but partly due to uncertainty as to where the natural boundary should be drawn, or whether it may not differ in different regions.

TABLE 2.—*List of shocks found to be normal or slightly deeper*
(Letter references are the same as in Table 1)

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
S 2 p	1931, Feb. 7	03:30:35	13 N.	87 W.	100?	CCCb
S 4 m	1933, Feb. 18	19:45:43	16½ N.	86 W.	80	BCBb*
S 5 m	1935, Nov. 23	07:52:30	½ N.	85½ W.	70	BBCh
S 8 m	1932, June 11	13:11:32	35 S.	71 W.	80	BCCb
S 10 d	1926, Oct. 3	19:38:01	49 S.	161 E.	100	BCCb
S 10 m	1938, Dec. 16	17:21:25	45 S.	167 E.	70	ABAh
S 14 b	1932, Dec. 3	06:19:52	15 S.	172½ W.	70	CCCb
S 14 d	1931, July 20	08:30:30	14 S.	173 W.	70	BCBb
S 14 i	1923, July 12	03:15:45	14½ S.	180	70	CCCb
S 14 m	1928, March 16	05:01:02	22 S.	170½ E.	80	ABBb
S 14 p	1932, Feb. 23	20:11:30	10 S.	162 E.	80	BCCb
S 14 r	1933, Nov. 18	03:54:00	7 S.	154½ E.	60	BCBb
S 21 h	1934, Feb. 14	01:21:13	6 S.	122½ E.	80	ACBb
S 21 p	1934, Jan. 1	06:16:40	8 S.	122 E.	70	BCCb
S 23 d	1932, April 22	04:58:08	4½ S.	103 E.	60	BCBb
S 23 h	1933, June 21	13:41:12	4 S.	102 E.	70	BBBbn
S 28 p	1932, Feb. 13	19:12:30	13½ N.	146 E.	90	CCCb
S 29 g	1933, Jan. 4	01:25:01	26 N.	144 E.	70	ACBb
S 29 k	1933, June 6	06:44:50	27 N.	143½ E.	70	BCCb
S 29 n	1933, Aug. 15	02:57:59	29 N.	143½ E.	70	ABBb
S 29 t	1932, May 11	06:53:35	33 N.	142 E.	60	BCCb
S 29 x	1933, June 18	13:11:25	30 N.	142 E.	80	BCCb
S 31 t	1939, Sept. 14	09:01:06	12 N.	95 E.	100	CBCh
S 35 m	1930, April 21	11:50:56	56½ S.	26 W.	100	BBBb

* Huancayo has P at 19:51:53.

SHALLOW EARTHQUAKES: STATISTICAL MATERIAL

For a discussion of the relative seismicity of various parts of the earth, there are available the lists already referred to (Tables 3, 4, and 5) together

TABLE 3.—*Revised epicenters of earthquakes*

January 1931–March 1934 with depths of less than 60 km. *See* text for "quality" and "class."

Day	Time	Latitude, degrees	Longitude, degrees	Quality	Class
1931					
Feb. 10	01:22:54	25.5 N.	96 E.	B	d
24	17:28:24	9.5 S.	117 E.	C	d
March 11	05:58:51	7 S.	131 E.	C	d
April 16	21:35:00	8 S.	158 E.	C	d
24	02:15:10	3 S.	103 W.	C	d
May 10	19:24:45	25 S.	116 W.	B	c
June 9	12:14:11	50½ N.	159 E.	C	c
	13:52:12	14 S.	174 W.	B	c
July 7	03:54:12	14 N.	96 W.	C	c
Sept. 15	21:08:50	45 S.	168 E.	B	d
Nov. 2	00:32:11	16 N.	96½ W.	A	c
26	2 shocks	61 S.	150 E.	C	d
Dec. 7	18:51:57	59 S.	148 E.	C	d
25	03:04:24	52 S.	141 E.	B	c
1932					
Jan. 17	07:45:05	12 S.	160.0 E.	C	c
18	13:12:33	45 N.	32.0 W.	C	d
22	00:48:56±	33 N.	47 E.	C	d
Feb. 16	13:48:50	15 S.	180	A	b
17	16:06:57	12 N.	73½ W.	A	d
21	13:20:57	4 N.	63 E.	C	d
March 5	01:40:54	36½ S.	178 E.	C	d
15	04:32:14	11 N.	144½ E.	A	c
	07:44:34	41 N.	45 E.	B	d
23	12:08:02	37 S.	99 W.	C	c
27	08:44:40	24½ N.	92 E.	B	d
28	00:35:34	8 S.	98½ E.	C	c
April 29	17:30:45	7 N.	127 E.	C	c
May 6	05:35:04	0	124 E.	C	d
31	08:37:24	7 N.	38 W.	B	d
June 6	11:49:56	19.6 N.	76.5 W.	B	c
14	11:20:15	18 N.	120 E.	B	c
July 11	08:21:31	12½ N.	124½ E.	B	c
Aug. 2	04:25:34	2.0 N.	126.0 E.	A	c
Sept. 9	06:46:25	1½ S.	128½ E.	B	d
Oct. 3	04:37:40	1 S.	91 W.	C	d
Nov. 27	03:37:28	29½ N.	143 E.	B	d
Dec. 16	07:14:24	7 N.	127 E.	B	c
1933					
Jan. 17	15:59:56	40 N.	97 E.	C	d
	18:47:47	34½ S.	59 E.	C	c
18	08:37:45	32 S.	19 W.	C	c
27	22:36:35	16 S.	172 W.	B	c

TABLE 3—*Continued*

Day	Time	Latitude, degrees	Longitude, degrees	Quality	Class
1933					
Feb. 16	09:08:12	2½ N.	126 E.	A	c
20	11:01:19	54 N.	164 E.	B	d
22	03:48:10	5½ N.	125 E.	C	d
27	16:10:02	57½ S.	145 E.	C	d
28	22:19:29	51 N.	30 W.	C	d
March 5	08:19:54	1 S.	128½ E.	C	c
6	13:05:35	26 N.	90½ E.	B	d
8	01:35:42	40 N.	143 E.	B	c
12	04:25:52	16 N.	86 ½ W.	C	d
23	17:38:20	48 N.	104 E.	C	d
April 1	08:07:35	6 N.	127 E.	C	d
4	12:09:38	17½ N.	60½ W.	C	d
16	06:00:03	33 S.	178 W.	C	d
25	22:37:54	71 N.	19 W.	C	d
May 5	04:14:11	49 N.	129 W.	B	d
16	01:12:28	7 N.	96½ E.	A	c
20	04:38:24	20 S.	174½ W.	B	c
30	11:43:36	8 N.	83 W.	B	d
June 1	17:19:57	4½ N.	94½ E.	C	d
2	12:20:56	1 S.	134 E.	C	d
6	02:28:22	14 N.	121 E.	A	c
10	11:26:59	17¼ N.	86¼ W.	A	d
18	03:53:58	15½ S.	172 W.	C	c
24	13:53:00	4 N.	126 E.	C	d
July 3	15:09:05	19½ N.	96½ E.	C	d
18	19:05:24	12 N.	139 E.	B	c
26	04:57:28	63.2 N.	147.3 W.	C	d
Aug. 20	22:59:22	13 S.	80 W.	C	d
26	01:30:29	28 N.	131 E.	C	d
28	22:19:40	59½ S.	25 W.	B	b
Sept. 6	01:15:46	58 S.	146 E.	C	c
12	12:53:33	8 N.	49 W.	C	d
15	16:19:50	28½ N.	131 E.	B	d
19	23:39:32	60 N.	138 W.	C	c
22	11:37:36	16½ S.	174½ E.	A	c
25	13:45:45	6 N.	126 E.	B	c
27	22:40:42	24 S	111 W.	C	d
Oct. 1	14:35:00	35 N.	142 E.	C	d
2	13:59:06	10 S.	166 E.	C	c
22	11:53:48	51 N.	156 E.	B	d
26	12:07:02	60 S.	60 W.	B	c
30	06:59:51	16½ S.	167½ E.	B	c
Nov. 4	08:41:17	8½ N.	72 W.	B	c
5	2 shocks	2 S.	80 W.	C	d
19	03:11:20	16½ S.	167½ E.	B	c
	09:08:29	25 N.	98 E.	C	d

TABLE 3—*Concluded*

Day	Time	Latitude, degrees	Longitude, degrees	Quality	Class
1933					
Dec. 2	05:17:18	52 S.	161 E.	C	c
	20:05:09	51 S.	50 W.	C	c
9	07:52:21	36½ N.	69½ E.	B	d
24	10:46:01	1 S.	150 E.	C	c
1934					
Jan. 16	04:59:27	27 N.	84 E.	C	d
20	17:56:08	41 N.	108 E.	B	c
29	12:34:43	37½ N.	144½ E.	A	d
Feb. 12	11:30:47	19 N.	101 E.	B	c
20	03:18:50	4 S.	105 W.	C	d
March 4	11:17:30	55 N.	164 E.	B	c
8	02:56:53	34 N.	26½ E.	B	d
	23:02:20	28 S.	68½ E.	C	d
9	14:02:23	65 N.	173 E.	C	d
21	03:39:50	35 N.	139½ E.	B	d

with the International Seismological Summary. It must be emphasized at once that the period of 36 years represented by Table 5 is extremely short from the geological point of view. In Table 3 the class designations are the same as those already given.

All shocks in Table 4 are of class *b*; those in Table 5 are of class *a*. In these tables, and throughout the paper, the letter given under "Quality" has the following meaning:

A epicenter probably located within 1 degree of arc.
B within 2 degrees.
C within 3 degrees.

In general, shocks which it did not appear possible to locate within 3 degrees have been omitted. However, in remote areas, particularly in the southern hemisphere, this tolerance has been extended somewhat, and such epicenters are also graded as of quality C.

The magnitudes given in Tables 4 and 5 are calculated from the amplitudes of surface waves at various stations. In general, the values thus found are accurate within ±0.4. (See Gutenberg and Richter, 1934, Fig. 6, p. 120.) Many shocks in Tables 4 and 5 have been made the subject of special investigations; references to these are given in footnotes to the tables. There may be others which have escaped our notice.

In adapting Table 5 from the previous list of large shocks (Gutenberg and Richter, 1936), several shocks have had to be omitted. Two of these are definitely established instances of deep focus—1911 June 15 (No. 138 p) and 1919 January 1 (No. 143). 1910 November 9 has been omitted

TABLE 4.—*Shocks with magnitude 7–7.7, January 1926–March 1934*

Day	Time	Revised epicenter		Quality	Magnitude
		Latitude, degrees	Longitude, degrees		
1926, Jan. 25	00:36:18	9 S.	158 E.	B	7.4
1926, Feb. 8	15:17:49	13 N.	89 W.	B	7.1
1926, March 27	10:48:30	9 S.	157 E.	B	7.1?
1926, April 12	08:32:28	10 S.	161 E.	B	7.7
1926, Oct. 26	03:44:41	3¼ S.	138½ E.	A	7.5
1927, Jan. 24	01:05:43	16½ S.	167½ E.	B	7.0?
1927, March 3	01:05:09	6 S.	122 E.	A	7.0?
1927, Aug. 5	21:12:55	37½ N.	142½ E.	A	7.2
1927, Aug. 10	11:36:15	1 S.	131 E.	B	7.2
1927, Sept. 11[1]	22:15:47	44½ N.	34½ E.	A	6.9?
1927, Oct. 24[2]	15:59:55	57½ N.	137 W.	A	7.2
1927, Nov. 4[3]	13:50:43	34½ N.	121½ W.	A	7.0
1927, Nov. 21	23:12:25	44½ S.	73 W.	B	7.0
1927, Dec. 28	18:20:23	55 N.	161 E.	B	7.1
1928, March 9	18:05:27	2½ N.	88½ E.	A	7.4
1928, March 16	05:01:02	22 S.	170½ E.	A	7.4
1928, March 22	04:17:00	16 N.	96 W.	B	7.1
1928, May 14	22:14:46	5 S.	78 W.	A	7.1
1928, May 27	09:50:26	40 N.	142½ E.	A	7.0
1928, June 29	22:49:38	15 S.	170½ E.	A	7.2
1928, Aug. 4	18:26:16	16 N.	97 W.	A	7.3
1928, Oct. 9	03:01:08	16 N.	97 W.	A	7.4
1928, Dec. 19	11:37:10	7 N.	124 E.	A	7.2
1929, Feb. 22	20:41:46	11 N.	42 W.	A	7.0
1929, March 7	01:34:39	51 N.	170 W.	A	7.3
1929, May 1	15:37:30	38 N.	58 E.	A	7.4
1929, June 13	09:24:34	8½ N.	127 E.	A	7.0
1929, June 16[4]	22:47:32	41¾ S.	173¼ E.	A	7.3
1929, July 5	14:19:02	51 N.	178 W.	A	7.0
1929, July 7	21:23:12	52 N.	178 W.	A	7.3
1929, Nov. 18[5]	20:31:58	44 N.	56 W.	A	7.0
1930, May 5[6]	13:45:57	17 N.	96½ E.	A	7.3
1930, May 6	22:34:23	38 N.	44½ E.	A	7.2
1930, June 11	00:49:35	5½ S.	150 E.	B	7.2
1930, July 2[7]	21:03:42	25½ N.	90 E.	A	7.2

[1] *See* Obruchev, *et al.* (1928).

[2] H. Sommer (1931) gives 0 = 15:59:55 ± 2 seconds, epicenter at 57° 26′ ± 50′ North, 137° 03′ ± 19′ West.

[3] P. Byerly (1930) has investigated the macroseismic and microseismic data of this shock. He finds 0 = 13:50:53, epicenter 34° 32′ North, 121° 24′ West.

[4] The records of this shock have been studied by several authors. Lehmann (1930) has chosen 41¾° S., 172¼° E. as epicenter. Bastings (1933) has interpreted the records as due to a sequence of three disturbances, following each other within 7 seconds, the last being the strongest with an energy of the order of 10^{24} ergs; 0 = 22:47:35, epicenter at 41° 43′ S., 172° 15′ E. The macroseismic data have been studied by Henderson (1937).

[5] Hodgson and Doxsee (1930) place this shock at 44.5° N., 55° W. with an origin time at 20:31:55. They give data on a large number of cable breaks produced by this shock. Additional effects and the geology of the region have been discussed by Keith (1930).

[6] Visser (1934) gives 0 = 13:45:41, epicenter at 17.2° N., 96.7° E.

[7] *See* Gee (1934).

TABLE 4.—*Concluded*

Day	Time	Revised epicenter		Quality	Magnitude
		Latitude, degrees	Longitude, degrees		
1930, Oct. 24[8]	20:15:11	18½ N.	147 E.	A	7.0
1930, Nov. 25[9]	19:02:47	35 N.	139 E.	A	7.0?
1930, Dec. 3[10]	18:51:44	18 N.	96½ E.	A	7.2
1931, Jan. 27	20:09:21	25.4 N.	96.8 E.	A	7.6
1931, Jan. 28	21:24:10	11.1 N.	145.0 E.	A	7.4
1931, Feb. 10[11]	06:34:32	5.3 S.	102.5 E.	A	7.1
1931, March 9	03:48:57	40.5 N.	142.5 E.	A	7.3
1931, March 18[12]	08:02:25	32.8 S.	71.3 W.	B	7.2
1931, March 18	20:13:42	5.6 N.	126.3 E.	A	7.0
1931, April 24	17:22:18	6.6 S.	155.2 E.	B	7.0
1931, Aug. 7	02:11:37	3.0 S.	143.5 E.	B	7.2
1931, Aug. 27[13]	15:27:25	29.8 N.	67.3 E.	A	7.0
1931, Sept. 25[14]	05:59:52	5.1 S.	102.7 E.	A	7.3
1931, Oct. 3[14]	19:13:19	10.6 S.	161.7 E.	A	7.6
1931, Oct. 10[14]	00:19:59	9.9 S.	161.4 E.	A	7.4
1931, Nov. 2	10:03:09	32.4 N.	132.1 E.	A	7.4
1932, Jan. 29	13:41:18	6.2 S.	155.0 E.	B	7.0
1932, June 22	12:59:32	19.1 N.	104.5 W.	A	7.0
1932, Sept. 15[15]	13:54:55	39.2 S.	178.2 E.	A	7.0
1932, Dec. 4	08:11:19	2.4 N.	121.0 E.	A	7.1
1932, Dec. 21[16]	06:10:12	38.7 N.	117.9 W.	A	7.3
1932, Dec. 25	02:04:31	39.2 N.	96.4 E.	B	7.7
1933, Jan. 21	19:21:14	34.0 S.	57.0 E.	B	7.0
1933, Feb. 23	08:09:19	20.0 S.	70.2 W.	A	7.2
1933, April 27	02:36:11	61.2 N.	150.9 W.	B	7.0
1933, June 18	21:37:36	38.5 N.	142.8 E.	A	7.3
1933, June 24	21:54:51	5.0 S.	104.2 E.	B	7.3
1933, Aug. 25	07:50:33	31.7 N.	103.4 E.	A	7.3
1933, Aug. 28	22:19:40	59.5 S.	25 W.	B	7.3
1933, Nov. 20[17]	23:21:38	73.3 N.	70.7 W.	A	7.4
1934, Feb. 24	06:23:47	22.8 N.	143.9 E.	A	7.1
1934, March 5[18]	11:46:19	40.4 S.	175.6 E.	B	7.3
1934, March 24	12:04:34	9.9 S.	161.4 E.	B	7.0

[8] Lehmann and Plett (1932) have studied seismograms of this shock; they have taken 0 = 20:15:11, with an epicenter at 18.4° N., 146.8° E.

[9] A summary of observations with references has been published by Davison (1936, p. 240-265). Among these note especially papers by Imamura (1931) and Kunitomi (1931).

[10] *See* Brown and Leicester (1933).

[11] *See* Gutenberg and Richter (1934).

[12] *See* Bobillier (1933).

[13] *See* West (1934).

[14] *See* Gutenberg and Richter (1934).

[15] *See* Hayes (1937).

[16] *See* Byerly (1935).

[17] *See* Lee (1937); Rajko and Linden (1935). Amplitudes of surface waves depend much on the azimuth of the station, causing differences in the calculated magnitude by about ± 1.

[18] *See* Bullen (1938).

because the imperfect data suggest a considerable depth of focus, which it is impossible to confirm or determine precisely. Three shocks—1907 October 21, 1910 December 13, and 1921 September 11—have been omitted as being smaller than the others on the original list. Shocks later than May 30, 1935 have been added.

References and material on some of the great shocks of Table 5 will be found in Davison (1936). The following are reported to have been accompanied or followed by tsunamis (seismic sea waves): 1904, June 25; 1906, September 14; 1907, January 4 and April 15; 1918, August 15; 1922, November 11 (*see* Gutenberg, 1939); 1923, February 3 (destructive in Hawaii); 1923, September 1 (comparatively small); 1933, March 2 (Ishimoto, *et al.*, 1934); 1939, April 30. There is no such report for that of 1932, June 2; but its large aftershock on June 22 (Table 4) was so accompanied.

For determining epicenters and origin times of many of the earlier shocks, use was made of individual station bulletins and of the summary publications by Szirtes (1909; 1910; 1912).

Four very great shocks have been assigned magnitudes near $8\frac{1}{2}$ and clearly exceed the others in the list: 1906, January 31; 1911, January 3; 1920, December 16; and 1922, November 11.

It will be noticed that Table 5 includes no shock for 1908, 1909, or 1910. Numerous available reports for these years have been examined without identifying any shock large enough for inclusion, although there are a few which fall just below the line.

One shock only is listed between 1912 and 1917. For 1913 it is reasonably certain that no very large shallow shock occurred, as all the principal stations were in operation, and the data have been collected and digested by Turner (1917). For the war years, particularly for 1915, the available data are imperfect, and a large shock in some remote region may have been missed, in spite of the collection of data by Turner. The regular publication of the International Summary in its full form begins for the year 1918.

No shocks of magnitude approaching 8 occurred in 1936 or 1940. This is quite positive, as careful attention was given to all the larger shocks as they occurred. The disastrous earthquake in Chile in 1939 (January 25) does not appear in the list because of its focal depth of about 70 km.

The first shock probably of class *a* after 1939 occurred on June 26, 1941, at 11:52 near the Andaman Islands.

Shocks of classes *a*, *b*, *c* for the period January 1933 to March 1934, and all shocks in Tables 4 and 5, are plotted on Figure 2. This map gives a fair representation of the present distribution of seismic activity at shallow depth. It is probably somewhat imperfect in the Southern Hemisphere, although care has been taken to minimize this. The cataloguing is good enough to make it certain that the greater activity of the Northern Hemi-

TABLE 5.—*Shocks of magnitude 7¾–8½, 1904–1940*

Day	Time	Epicenter Latitude, degrees	Epicenter Longitude, degrees	Magnitude	Quality	Region
1904, June 25[1]	21:00.5	52 N.	159 E.	8	C	Kamchatka
1905, April 4[2]	00:50.0	33 N.	76 E.	7¾	B	Kangra, India
1905, July 9[3]	09:40.4	49 N.	99 E.	8	C	SW. of Lake Baikal
1905, July 23[3]	02:46.2	49 N.	98 E.	8	C	SW. of Lake Baikal
1906, Jan. 31[4]	15:36.0	1 N.	81½ W.	8½	B	Colombia-Ecuador
1906, April 18[5]	13:12.0	38 N.	123 W.	8¼	B	San Francisco
1906, Aug. 17[6]	00:10.7	51 N.	179 E.	8	C	Aleutian Islands
1906, Aug. 17[6]	00:40.0	33 S.	72 W.	8¼	C	Chile
1906, Sept. 14[7]	16:04.3	7 S.	149 E.	8	C	New Guinea
1907, Jan. 4[8]	05:19.2	2 N.	94½ E.	8	B	Sumatra
1907, April 15[9]	06:08.1	17 N.	100 W.	7¾	B	Guerrero, Mexico
1911, Jan. 3[10]	23:25.7	43½ N.	77½ E.	8½	B	Tien-Shan
1911, Feb. 18[11]	18:41.1	40 N.	73 E.	7¾	B	Pamir
1911, Aug. 16[12]	22:41.4	9 N.	138 E.	8	C	Caroline Islands
1912, May 23[13]	02:24.1	21 N.	97 E.	8	C	Burma
1912, Aug. 9[14]	01:29.0	40½ N.	27 E.	8	B	Turkey
1914, May 26	14:22.7	3 S.	138 E.	8	C	New Guinea
1915, Oct. 3[15]	06:52.8	40½ N.	117½ W.	7¾	A	Nevada
1917, May 1[16]	18:26.6	31 S.	179 W.	8	C	Kermadec Islands
1917, June 26[17]	05:49.7	15½ S.	173 W.	8¼	B	Tonga Islands
1918, Aug. 15[18]	17:30.2	5½ N.	126 E.	8	A	Philippine Islands
1918, Sept. 7	17:16.2	45½ N.	151½ E.	7¾	B	Kurile Islands
1919, April 30	07:17.1	19 S.	172½ W.	8	B	Tonga Islands
1919, May 6	19:41.2	5 S.	154 E.	8	B	Bismarck Islands
1920, June 5	04:21.5	23½ N.	122 E.	7¾	A	Formosa

[1] *See* Rosenthal (1906, 1907). A considerable group of earthquakes; the largest is that given in the table. Of the foreshocks, one, at 14^h was also of magnitude 7¾ to 8. Of the many aftershocks that on June 27 at 0^h was almost as large as the shocks of June 25. Some damage at Petropavlovsk.

[2] *See* Middlemiss (1910); Omori (1907a).

[3] *See* Sieberg (1932a, p. 789). Violent in the eastern Tannu-ola area.

[4] *See* Rudolph and Szirtes (1912).

[5] *See* Lawson, *et al.*, (1908).

[6] Two great earthquakes occurred about half an hour apart. For the earlier, in the Aleutian Islands, our only information is taken from seismograms; the latter was the destructive Valparaiso earthquake. *See* Rudolph and Tams (1907), with reproduction of principal seismograms.

[7] Many landslides and a seismic sea wave. *See* Sieberg (1910; summarized 1932a, p. 911).

[8] Violent on the islands Simeuloe and Nias, off the coast of Sumatra.

[9] *See* Boese, *et al.* (1908). Very destructive.

[10] *See* Galitzin (1911).

[11] Jeffreys (1923) is a discussion of the mechanical connection between this shock and a great landslide in the Pamir region which accompanied it. Later opinion, to which Jeffreys has also subscribed, accepts the landslide as an effect of the earthquake.

[12] Epicenter from readings at Apia, Berkeley, Göttingen, Osaka, and Jena. Strong at Yap (Sieberg, 1932a, p. 919).

[13] Based on reports from Osaka and European stations.

[14] Destructive on the north coast of the Sea of Marmora. *See* Sieberg (1920; 1932a, p. 758). Epicenter from macroseismic data, consistent with instrumental observations.

[15] Epicenter from macroseismic data. This shock was accompanied by formation of fault scarps about 14 feet in height in Pleasant Valley, south of Winnemucca, Nevada (Jones, 1915). For a later study including the scarps formed in 1915 *see* Page (1935).

[16] Possibly deeper than normal.

[17] Instrumental epicenter by Gutenberg (1925). Violent in the Tonga and Samoa Islands (Sieberg, 1932a p. 923).

[18] Violent in southern Mindanao (Masó, 1918).

TABLE 5.—*Concluded*

Day	Time	Epicenter		Magnitude	Quality	Region
		Latitude, degrees	Longitude, degrees			
1920, Dec. 16[19]	12:05.8	36 N.	105 E.	$8\frac{1}{2}$	A	Kansu, China
1922, Sept. 1[20]	19:16.1	$24\frac{1}{2}$ N.	122 E.	8	A	Formosa
1922, Nov. 11[21]	04:32.6	$28\frac{1}{2}$ S.	70 W.	$8\frac{1}{2}$	A	Chile
1923, Feb. 3	16:01.7	54 N.	161 E.	$8\frac{1}{4}$	A	Kamchatka
1923, Sept. 1[22]	02:58.6	$35\frac{1}{4}$ N.	$139\frac{1}{2}$ E.	8	A	Japan
1924, April 14[23]	16:20.4	$6\frac{1}{2}$ N.	$126\frac{1}{2}$ E.	8	A	Philippine Islands
1924, June 26[24]	01:37.6	56 S.	$157\frac{1}{2}$ E.	$7\frac{3}{4}$	B	SW. of Macquarie Island
1927, March 7[25]	09:27.6	$35\frac{3}{4}$ N.	$134\frac{3}{4}$ E.	$7\frac{3}{4}$	A	Japan
1927, May 22[26]	22:32.7	$36\frac{3}{4}$ N.	102 E.	$7\frac{3}{4}$	A	Kansu, China
1928, June 17[27]	03:19.6	$16\frac{1}{4}$ N.	98 W.	$7\frac{3}{4}$	A	Oaxaca, Mexico
1928, Dec. 1[28]	04:06.2	35 S.	72 W.	8	A	Chile
1929, June 27[29]	12:46.9	54 S.	$29\frac{1}{2}$ W.	$7\frac{3}{4}$	B	South Atlantic
1929, Dec. 17	10:58.5	$52\frac{1}{2}$ N.	$171\frac{1}{2}$ E.	$7\frac{3}{4}$	A	Aleutian Islands
1931, Jan. 15[30]	01:50.8	$16\frac{1}{2}$ N.	$96\frac{1}{2}$ W.	8	A	Oaxaca, Mexico
1931, Feb. 2[31]	22:46.8	$39\frac{1}{2}$ S.	177 E.	$7\frac{3}{4}$	A	New Zealand
1931, Aug. 10[32]	21:18.8	47 N.	90 E.	8	B	Altai Mountains
1932, May 14[33]	13:11.1	$\frac{1}{2}$ N.	126 E.	$7\frac{3}{4}$	A	Celebes
1932, June 3[34]	10:36.9	19 N.	104 W.	8	A	Mexico
1933, March 2[35]	17:31.0	39 N.	$144\frac{1}{2}$ E.	$8\frac{1}{4}$	A	Japan
1934, Jan. 15[36]	08:43.3	$26\frac{1}{2}$ N.	86 E.	$8\frac{1}{4}$	B	India
1934, July 18	19:40.1	15 S.	167 E.	8	B	Santa Cruz Islands
1935, May 30[37]	21:32.7	$29\frac{1}{2}$ N.	67 E.	$7\frac{3}{4}$	B	Quetta, Baluchistan
1935, Sept. 20	01:46.7	2 S.	142 E.	$7\frac{3}{4}$	B	New Guinea
1935, Dec. 28	02:35.4	$\frac{1}{2}$ S.	98 E.	$7\frac{3}{4}$	A	Off Sumatra
1937, Jan. 7	13:20.6	$35\frac{1}{2}$ N.	98 E.	$7\frac{3}{4}$	A	Kuenlun Mts.
1938, Feb. 1[38]	19:04.5	5 S.	$131\frac{1}{2}$ E.	8	B	New Guinea
1938, Nov. 10	20:18.7	$55\frac{1}{2}$ N.	158 W.	$8\frac{1}{4}$	B	Alaska
1939, April 30	02:55.5	$10\frac{1}{2}$ S.	$158\frac{1}{2}$ E.	8	B	Solomon Islands
1939, Dec. 26[39]	23:57.4	$39\frac{1}{2}$ N.	$38\frac{1}{2}$ E.	8	A	Turkey

[19] Great landslides and heavy loss of life. *See* Close and McCormick (1922); Dammann (1924).

[20] *See* Omori (1923).

[21] *See* Willis (1929); Gutenberg (1939).

[22] *See* Davison (1931) with numerous references which should be consulted.

[23] *See* Masó (1924).

[24] Instrumental study by Macelwane (1930).

[25] Tango earthquake. Two intersecting fault traces formed. For references *see* Davison (1936).

[26] Epicenter west of that of December 16, 1920; great destruction and loss of life.

[27] Strong foreshock on March 22; among the aftershocks were two major earthquakes on August 4 and October 9 (Table 4).

[28] Destructive at Talca and Chillán.

[29] *See* Tams (1930a; 1930b).

[30] *See* Ordoñez (1931).

[31] The Hawkes Bay earthquake. *See* Adams, *et al.* (1933), Davison (1936). Short illustrated note by Townley (1931).

[32] Violent at the few places of habitation near the instrumentally determined epicenter (Lee, 1933).

[33] Destructive on northern Celebes and Ternate, with considerable loss of life.

[34] Destructive in the region of Guadalajara and Colima. Many strong aftershocks.

[35] *See* Matuzawa (1935; 1936).

[36] Felt over almost the whole of India. Particularly destructive in the state of Bihar, and at Khatmandu in Nepal (Dunn, *et al.* 1939; Nasu 1935).

[37] This shock almost completely destroyed the city of Quetta, Baluchistan, with a loss of about 30,000 lives. (West, 1935; 1936). Much smaller than the Indian earthquake of 1934. Ramanathan and Mukherji (1938) assign a magnitude of 7.3. Amplitudes at European stations and Pasadena suggest a magnitude near 7.7.

[38] Felt in the Moluccas and New Guinea, and at Port Darwin, Australia, which is about 800 kilometers (about 500 miles) from the epicenter.

[39] *See* Salomon-Calvi (1940). Heavy loss of life.

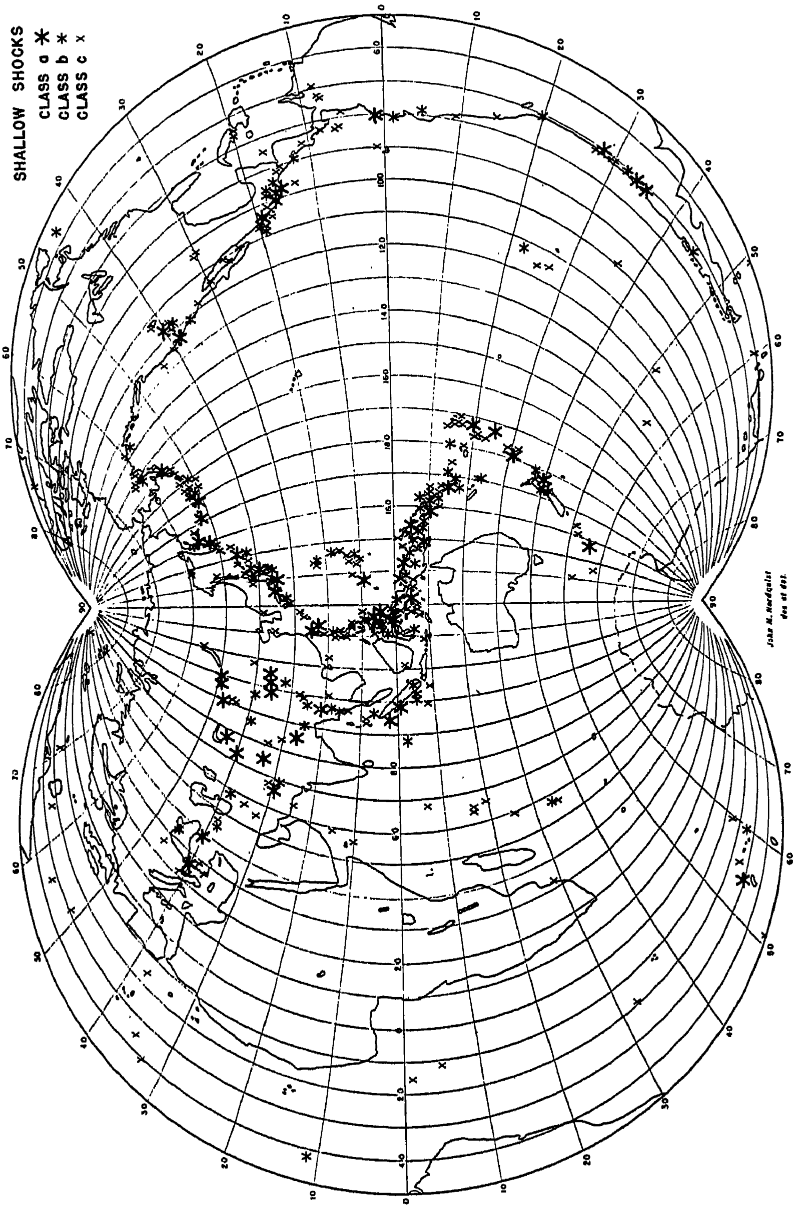

Figure 2.—*World map of shallow earthquakes*

Class *a* 1904-1940; class *b* 1926-March 31, 1934; class *c* 1931-March 31, 1934, with a few omissions in active regions

sphere compared with the Southern is real, and is not simply due to the distribution of stations. Class *d* shocks are omitted from Figure 2, as shocks of this class can be located only when they are not too distant from good stations. Shocks of class *e* probably occur in all parts of the world, and are excluded from the present study.

GENERAL GEOGRAPHICAL DISTRIBUTION

Figures 1 and 2 together represent the present state of our knowledge of the distribution of seismicity, as shown by recent earthquakes. However, in Figure 1 the deep-focus shocks are mapped without reference to magnitude, and the indicated distribution is much affected by the position of stations; this accounts in large measure for the apparent concentration of such shocks in the vicinity of Japan.

Inspection of the two figures shows the main outlines of geographical distribution. When these are supplemented by the additional data presented in later tables and figures, it becomes apparent that epicenters for all but the smallest earthquakes may be divided geographically into four distinct groups:

(1) The circum-Pacific belt or zone, with many branches and subdivisions. This belt, as defined in the present paper, includes a large majority of shallow shocks, a still larger fraction of the intermediate shocks, and all the deep shocks in the restricted sense.

(2) The Mediterranean and trans-Asiatic zone. This area includes the remainder of the largest shallow shocks (class *a*), and all the remaining intermediate shocks.

(3) Other narrow belts, including only shallow shocks. One of these extends through the Arctic and Atlantic oceans, another through the western Indian Ocean. The shocks of the East African Rift will be discussed with this group.

(4) Scattered shocks or groups of shocks, all shallow.

These groups will be taken up in order. In discussing each individual area, all the material available, including all epicenters given in the various tables, will be used. Accordingly, the additional epicenters plotted on the several regional maps cannot be used for statistical purposes, since they have been selected in a different way for a different purpose. It must be emphasized that this selection has been regional and uniform over entire areas. Special search was made for epicenters in unusual locations. Epicenters appearing to fall out of line have been examined as carefully as those occurring in the principal active belts, and have been rejected only when the data were manifestly imperfect. The occurrence of epicenters in well-defined lines and belts is an immediate consequence of the data, without any forcing, which has been scrupulously avoided. Finally, in regions where the activity was already well outlined by larger

earthquakes, shocks of class *d* were included only for the period January 1931 to March 1934.

Certain areas are conspicuously inactive. These are the Pacific basin and the continental shields. They will be discussed following the active belts, and this discussion will cover some of the scattered groups of shocks already mentioned. The remainder of these scattered shocks fall into the areas, usually of complex structure, lying between the active belts and the stable shields.

THE CIRCUM-PACIFIC BELT

GENERAL SURVEY

The circum-Pacific belt, although practically continuous, includes segments and branches in which the activity is very dissimilar in character. Geographically remote segments often show striking analogies.

Between Alaska and central Mexico seismicity is relatively low, in spite of occasional large shocks, and consists exclusively of shallow earthquakes. The sector is unique in this respect, unless the same is true of the little-known and possibly very different sector between South America and New Zealand.

On the American side two loops extend eastward from the main line: the Caribbean or Antillean loop, and the South Antillean loop through the Falkland Islands and South Georgia. In both loops intermediate as well as shallow shocks occur.

The Pacific coast of South America is noteworthy for the comparative rarity of shocks at shallow depth, the considerable seismicity consisting very largely of intermediate earthquakes. Very deep shocks occur farther inland. Off the coast lies a moderately active belt, in which a few intermediate shocks accompany a majority of shallow shocks. This may possibly be a branch of the main belt.

On the opposite side of the Pacific there is a similar and unquestionable phenomenon of branching, as shown by the epicenters of shallow and intermediate shocks. The active belt extending from Alaska through the Aleutian Islands, Kamchatka and the Kurile Islands divides in central Japan. Its western branch leads through the Riu-Kiu Islands and Formosa to the Philippines, and its eastern branch leads southward to the Marianne Islands. In this eastern branch intermediate shocks are relatively more frequent than in the western branch. Parallel to the eastern branch runs a belt of deep foci—which, however, departs from it and continues across Japan and the Japan Sea into Manchuria, where it turns at right angles and extends northeastward parallel to the belt of shallow and intermediate activity.

The western branch appears to continue from the eastern Philippines through the Moluccas, round the Banda Sea, and by way of the Sunda

Islands into the Nicobar and Andaman Islands. Here it may possibly end; the connection through the epicenters in Burma with the trans-Asiatic active area is not certain.

The eastern branch can be followed by way of Guam along the andesite line (which separates the regions of prevailing andesitic and prevailing basaltic eruptive rocks) as far as Yap, in the western Carolines. Here there is a gap in the line of established epicenters. Structural conditions probably justify associating all this activity with the andesite line, which here continues to the vicinity of western New Guinea. From here eastward the belt of seismicity again parallels the andesite line, and turns abruptly southwestward with it between Samoa and the Tonga Islands; it passes New Zealand, and just south of Macquarie Island bends sharply west into a loop apparently analogous to that of the Southern Antilles. The active belt returns eastward on the south limb of this Macquarie Island loop, beyond which no epicenters are available to trace it. It may connect along the Easter Island Rise with the branch off South America.

In general, the Pacific belt of seismic activity separates the areas of continental structure from those of Pacific structure. Its association with the andesite line is an example of this. The oceanic area west of New Zealand and the Kermadec and Tonga Islands is evidently a part of the Australasian continental area. The open sea between the Marianne Islands and the Philippines, separating the eastern and western branches of the belt, covers a region of continental structure, if we rely on the evidence afforded by the velocities of seismic surface waves (Gutenberg and Richter, 1936). This area may perhaps include isolated fragmentary patches where the structure is Pacific or an approximation to it, particularly in the vicinity of the deeps along its western margin. Similar conditions may exist in the vicinity of the deeps off the South American coast. In the area between these latter deeps and the off-shore line of activity previously referred to, there is evidence for continental structure, derived chiefly from the amplitudes of reflection for bodily seismic waves (Gutenberg and Richter, 1935). There is some purely seismic evidence for the Pacific character of the Caribbean structures. Not only do shocks at intermediate depth occur in that region, but bodily waves reflected in the vicinity of Tampico show the small amplitudes characteristic of Pacific structures. (Gutenberg and Richter, 1935) No comparable data are available for other parts of this region.

Very deep shocks (at depths of 600 km. and more) are associated with both main branches of the circum-Pacific belt, where they change direction abruptly,—in and west of the Banda Sea, and southwest of Samoa. There is no similar structural environment for the similar shocks in South America, nor for those in the Japanese-Manchurian region.

ALEUTIAN ARC

The Aleutian structural arc is probably seismically active throughout its length, although the instrumental data of recent years show great differences in its various parts. The western end abuts against the very active region of Kamchatka; but from here eastward through the Commander (Komandorski) Islands activity is comparatively slight. The central part of the arc, opposite the Aleutian trough, is one of the most active areas of the globe, with very frequent shocks, some of them of the largest magnitudes. As may be seen from Figure 2, this activity diminishes only slightly eastward toward the Alaskan peninsula. The arc ends in the region of the Kenai Peninsula, where there is again considerable activity; shocks in this area are frequently felt sometimes causing damage at Seward and other neighboring points. The belt of activity continues northward, following the trend of the Alaska Range. Perhaps the shocks in the region of Fairbanks should also be included here; the most recent large one occurred on July 22, 1937 (Bramhall, 1938).

Except for the eastern end in Alaska, epicenters on the Aleutian arc are exclusively from instrumental data. Although the larger shocks of the group are well recorded at all the principal stations of the Northern Hemisphere, location is usually only reasonably good. In some cases this is evidently due to complexity in the shock, leading to imperfect or confused seismograms. In other instances difficulty appears to result from a focal depth slightly deeper than usual for shallow earthquakes (say 50 km.). A few cases of intermediate focus are positively identified (Fig. 1), and many others are suspected.

Most of the better determined epicenters lie on the south side of the structure, between the islands and the Aleutian trough; a few of them lie farther north, even among the islands. The epicenters of the intermediate shocks fall among this northern group. This appears to be an instance of the phenomenon which is well developed along other Pacific coasts, that the shallow shocks fall farther out to sea than the intermediate ones.

The seismic history of the region is imperfectly known. Shocks have been reported felt at Unalaska and other points since the earliest explorations. For the Aleutian Islands, west of Unalaska, most of the data consist of occasional reports of shocks felt on shipboard. For the Alaskan region the state of macroseismic information is well indicated on a map by Sieberg (1932a, p. 938). For recent years macroseismic data for Alaska are summarized by the United States Coast and Geodetic Survey in publications under the serial head *United States Earthquakes*.

ALASKA TO MEXICO

This sector extends from central Alaska to central Mexico. In strong contrast with the constant activity and frequent large shocks characteristic

of central Alaska and the west coast of central Mexico, most parts of the intervening sector exhibit a continuous minor activity, punctuated by large shocks at comparatively long intervals. All these shocks are shallow; in the Californian area the instrumental records strongly indicate that the typical shocks have a depth appreciably less than that usual in other parts of the world; this depth is not always accurately determined, but seems rarely to exceed 15 km. As a consequence, the intensity manifested near the epicenter is relatively high, and the disturbed area relatively small, for shocks of a given magnitude. In several instances, faulting has been observed at the surface.

While the activity here is low compared with the rest of the Pacific belt, it is appreciably higher than for most of eastern North America. Although the historical record of earthquakes begins as late as 1769, a long series of shocks is known, many of which were locally destructive (Townley and Allen, 1939). Of the largest shocks, two (those of 1906 and 1915) are indicated on Figure 2. Two others of comparable magnitude are known to have occurred; one in 1857 in Southern California, and one in 1872 in Owens Valley, east of the Sierra Nevada. With these may be mentioned the great shock of 1899 in Yakutat Bay, Alaska (Tarr and Martin, 1912).

Between Alaska and northern California the principal epicenters lie off the coast; however, they are still within the continental area. This is definitely indicated by data on the propagation of seismic waves in this region (*see* Gutenberg and Richter, 1935), and is consistent with the fact that the structural trend lines of California strike out to sea toward the north. For discussion of this region *see* Byerly (1940). Farther south the principal belt of activity trends inland. As in other parts of the world, this apparent single active belt is somewhat complex in detail. *See* Richter (1940) and refer to the section on Minor Seismicity in this paper. In California it follows the general trend of the San Andreas fault, with its branches and parallel faults. These features are shown on the fault map of California, prepared by Willis and Wood in 1922 (Willis, 1923, map). More recently revised information as to the location of faults, but without indication of their activity, appears on the new geological map of California (Jenkins, 1938).

In Southern California the principal faults, their accompanying structures, and the seismically active belt are intersected and deflected by east-west structures and fault zones, also seismically active. The chief activity then extends from Imperial Valley down the Gulf of California, with some epicenters on the peninsula of Baja California.

The eastward offset of structures and activity is not followed by the margin of the continental shelf which continues with a roughly linear trend off the coast of Southern California. Between it and the mainland

is an area of considerable submarine relief, with five large islands and some small rocks; this area manifests moderate seismic activity. Still farther southwest is the epicenter of the shock of January 4, 1933, mapped on Figure 2 at 28°.5 N. 127° W. This is a very well located epicenter, but whether it should be considered as a Pacific shock or as a continental shock remains somewhat uncertain, as there is no assurance that the margin of the continental shelf is actually the boundary between Pacific and continental crustal structure. Along the entire coast between Alaska and central Mexico there are no oceanic deeps, such as mark the margin of the Pacific elsewhere.

In this discussion, earthquakes in Owens Valley and Nevada have been included with the Pacific belt. While these shocks occur in a district somewhat remote from the coast, the association is natural.

MEXICO AND CENTRAL AMERICA

The Pacific coastal lands of central Mexico rank with the Aleutian arc among the most active sources of shallow earthquakes (Fig. 3). The distribution of epicenters on our maps is affected by high activity in 1931 in Oaxaca and in 1932 in Jalisco. The intervening coast has been very active in other years, as exemplified by the large Guerrero earthquake of 1907.

The east-west belt of shocks at intermediate depth (mostly near 100 km.) across central Mexico follows a zone of active volcanism. Some of these shocks have been destructive—such as that of February 10, 1928 in Puebla, and that of July 26, 1937 in Vera Cruz. Destructive shocks in earlier years along this line may have had equal focal depth.

Note that the coastal belt of shallow shocks apparently turns southward off shore in western Panama; eastern Panama, including the Canal Zone, is comparatively inactive. The epicenters far off the coast near 100° W. are to be considered in connection with those of the Galapagos Islands and southward.

In the volcanic zones of Central America there are frequent shocks originating near the surface, often very destructive in limited areas. However, the principal inland activity is at intermediate depth (down to 200 km.). The shocks in the Gulf of Honduras, near the limit between shallow and intermediate depth, suggest a branching of the main Pacific active belt, and a connection with the West Indian activity.

CARIBBEAN LOOP

The Caribbean seismic loop (Fig. 3) diverges from the main circum-Pacific belt near the Isthmus of Tehuantepec. It strikes out through the Gulf of Honduras, along the margins of the Bartlett Deep to Cuba and Haiti, and thence round the Atlantic side of the Lesser Antilles to the South American coast. Here it gradually trends inland, and follows the

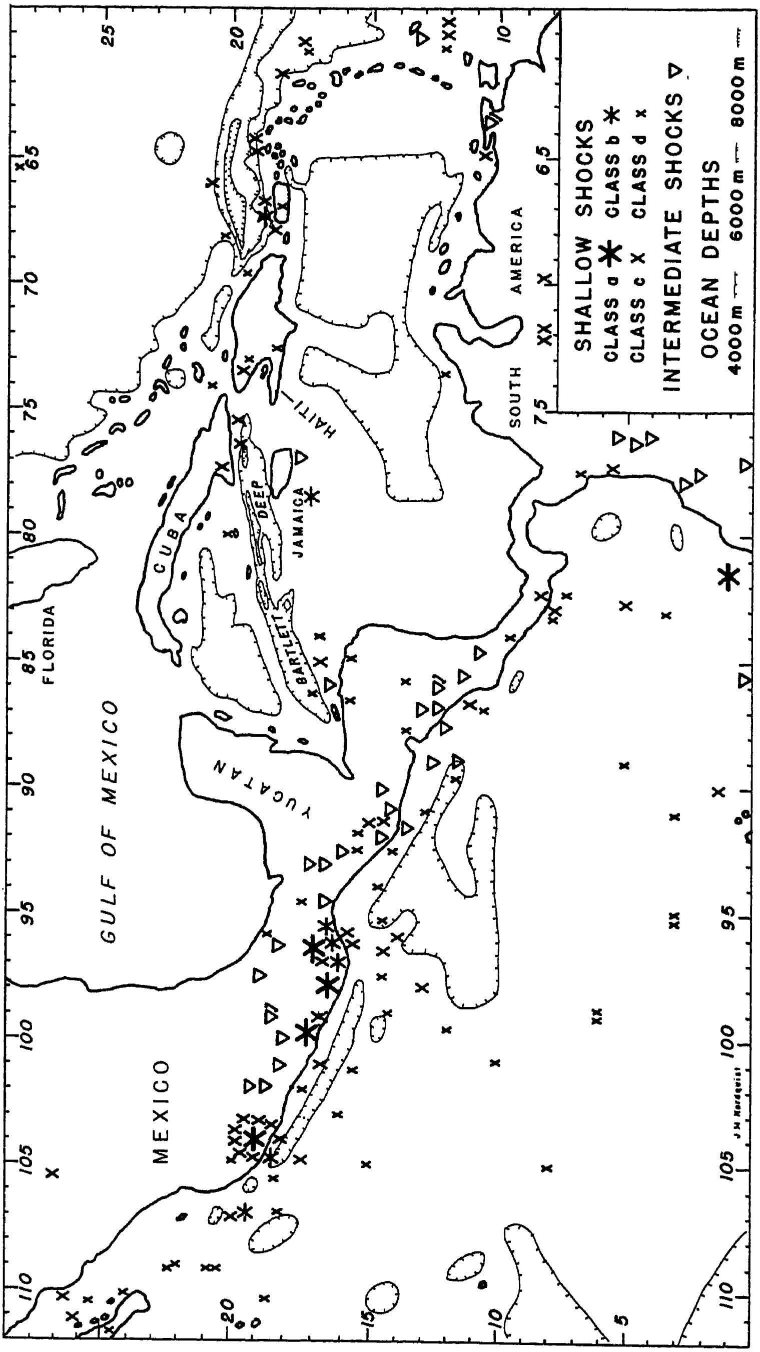

FIGURE 3.—*Map of epicenters, Mexico and Caribbean region*

northern Andean structures through Venezuela into Colombia, where it becomes identified with the main Pacific belt.

On the west, the loop is closed off by the Central American structural and seismic belt; on the east, there is not the slightest evidence of an

TABLE 6.—*Additional earthquake epicenters in the Caribbean region*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, Jan. 17	11:45:39	10½ N.	64½ W.	B	c
1922, May 11	06:45:35	12 N.	59½ W.	B	c
1928, Sept. 27	00:44:05	12 N.	60 W.	A	c
1925, July 7	17:43:43	17½ N.	60½ W.	B	c
1925, Sept. 29	17:33:50	18½ N.	62 W.	B	c
1927, Aug. 2	00:51:46	19 N.	64½ W.	A	c
1918, Oct. 11	14:14:30	18½ N.	67½ W.	A	b
1922, Dec. 18	12:35:03	19 N.	67 W.	B	c
1920, Feb. 10	22:07:15	18 N.	67½ W.	B	c
1926, March 24	05:41:21	19½ N.	69½ W.	C	d
1923, Nov. 3	08:37:46	19½ N.	73½ W.	B	c
1923, March 15	06:03:12	20 N.	68 W.	C	d
1930, June 25	12:06:20	19 N.	64 W.	B	c
1924, Jan. 30	20:54:48	20 N.	77½ W.	C	d
1934, July 10	01:02:10	20 N.	80 W.	B	d
1939, June 12	04:05:09	20½ N.	66 W.	A	c
1938, Nov. 10	15:23:30	20¾ N.	74 W.	B	d
1938, April 13	13:53:13	12 N.	60½ W.	C	d
1939, Nov. 7	15:44.0	18 N.	72½ W.	B	d
1939, March 7	11:20:49	18 N.	67 W.	B	d
1940, Nov. 10	20:40:27	17 N.	84 W.	C	d
1941, April 7	23:29:17	17¾ N.	78½ W.	A	b

active belt extending from the Lesser Antilles across the Atlantic, as indicated on most old seismic maps of the world.

Activity here is low compared to that of most of the circum-Pacific belt, though it is higher than that of many other regions. It apparently resembles that in California. During four centuries of recorded history, many earthquakes, some extremely destructive, are known to have occurred thus giving the West Indies a reputation for high seismicity which is not altogether deserved.

Instrumentally determined epicenters can be supplemented from the history of destructive shocks, but careful discrimination is required. (*See*, Sieberg, 1932a, p. 961–974; Scherer, 1912; and Taber, 1920; 1922.)

In general, macroseismic and historical data support the assumption of one continuous active belt, though this may be subdivisible laterally, as Taber indicates. A conspicuous exception was the destructive earth-

quake of 1880 at San Cristóbal in western Cuba. Taber (1922) points out that in the entire history of Cuba the only other strong shocks have been near Santiago. The most notable of these took place in 1678, 1755, 1766, and 1932.

Among the earthquakes of Jamaica were the two very destructive shocks of 1692 and 1907. Taber (1920) concludes that both originated off the north coast of the island. For Haiti we may note the shock of 1842, extremely destructive at Cap Haitien and neighboring points on the north coast, and those of 1751 and 1770, violent in the southern part of the island.

The instrumentally determined epicenter for the destructive Porto Rico earthquake of October 11, 1918, agrees well with macroseismic data. (*See* Reid and Taber, 1919a; 1919b.)

Historical data are of small value for the Lesser Antilles, since it is impossible to determine epicenters, except for small shocks of a strictly local volcanic character.

Of the shocks mapped as of intermediate depth, the two in Venezuela are at well-determined depths near 100 km. Depths for the others are less precise.

Recent surveys have demonstrated the existence of a belt of large negative gravity anomalies in this region. For discussion and references *see* Ewing (1938) and Hess (1938). This belt extends north of Haiti and Porto Rico, and on the Atlantic side of the Lesser Antilles; the earthquake epicenters lie in or close to it. Hess has postulated a former extension of this belt, indicated by serpentinite intrusions where high gravity anomalies no longer exist; this extension passes by way of Cuba and Yucatan into Mexico and is now seismically inactive, unless the Cuban shock of 1880 is referred to it.

ANDEAN ZONE

This includes epicenters near the Pacific coast as well as those in the Andes proper (Fig. 4). The mapping of shallow shocks is not statistically comparable with that of deeper shocks. All known intermediate and deep shocks are shown on this Figure, while the shallow shocks indicated for the Andean zone are only those of 1931–1933 and of Tables 4 and 5, with four additional epicenters as follows:

1936, May 22	00:15:58	32° S.	66° W.
1936, July 26	07:36:53	24° S.	70° W.
1937, Dec. 24	06:20:40	10½° S.	76½° W.
1940, Oct. 11	18:41:13	41½° S.	74½° W.

For these shocks the magnitude class is *c*, the quality of epicenter, is B, and the focal depth is probably slightly greater than that usual in other regions, say 40 to 50 km.

The fairly high seismicity of the Andean zone is due primarily to earthquakes at intermediate depth. Even the shocks designated as shallow in the present study frequently show evidence of focal depth greater than that found elsewhere. For the earlier years especially there is great difficulty in discriminating shallow shocks from intermediate earthquakes at depths of 70 to 100 km. This difficulty is diminished beginning about 1931 when a short-period vertical-component Benioff instrument was installed at Pasadena. The records of the station at Huancayo, Peru, which began operating in August, 1932, are also filed at Pasadena, and are of very great assistance in studying the depth of South American earthquakes. Further, beginning about 1931 there was general recognition of the occurrence of deep shocks, which were then more frequently reported as such, with details of the characteristic seismographic phases, by many stations. The period 1931–1933, for which all the shocks listed in the International Summary have been examined with care, is much more acceptable for statistical purposes. For these years 15 shallow shocks (not including small aftershocks) and 32 intermediate shocks have been located in the Andean zone. Because of their special interest, more effort was made to locate the intermediate shocks, and moreover they are often more clearly recorded than shallow shocks of the same energy. On the other hand, some of the shocks mapped as shallow in Figure 4 may prove to be intermediate.

Ample evidence now exists for the occurrence of shocks at intermediate depth, large enough to be very destructive at the surface. The great Chillán earthquake of January 25, 1939 at a depth of 70 km., has already been mentioned; its epicenter is marked by an arrow in Figure 4. Another striking case is the destructive Colombian earthquake of February 5, 1938, originating at a depth of 160 km. The vast extent of the perceptibly shaken areas in many South American shocks has long been a matter of remark; this is to be expected if the focus is deeper than ordinary. A related observation concerns the difficulty in drawing isoseismals for these earthquakes. Especially in Chile, where the centers of population are scattered, it has often been said that the apparent intensity bears a more evident relation to the character of the ground than to distance from the epicenter. (*See* Willis, 1929.) Such effects are very marked in cases of deep focus, both in South America and elsewhere. Finally, it is noteworthy that there is no credibly established instance in South America when surface faulting accompanied a great earthquake, although such instances are known from many other seismic regions. In some cases considerable changes of level, particularly at the coast, accompanied great shocks; such effects may have been the surface distortion occasioned by a deep-seated fracture.

Deep shocks in the restricted sense are comparatively rare; to date only 18 have been identified. Only one of these occurred during the period

1931–1933. Judging by the amplitudes of the seismic waves, several of these were shocks of very great energy. Some of them were reported felt, although the focal depth in each case is at least 600 km. Between these and the intermediate shocks, which extend down to 300 km. is a vacant range in focal depth. There is also a gap in the geographical distribution; the epicenters of the deep shocks are well to the east of all others in the zone. In the north they are completely out of the Andes, in western Brazil.

Epicenters of intermediate shocks are fairly generally scattered in the Andean zone down to about 40° S., being most numerous near 23° S., where there is a clear separation between shocks at about 67° W. at depths of about 200 km. under the major Andean chain, and shocks near 69° W. at depths of 100 to 150 km. under the coastal Cordillera. Elsewhere the deeper intermediate shocks generally occur farther from the coast than those of shallower depth; however, in Peru shocks at 150 km. or even deeper occur comparatively near the coast.

Shallow shocks, with two important exceptions, occur close to the coast or even offshore. All these shocks are to be considered as shallow with the reservation that they probably belong in the deeper part of that range, from 40 to 60 km.

Four of the mapped shocks are among the great shocks of Table 5. The data exclude depths of as much as 100 kilometers. Four shocks are taken from Table 4. Of these, that of May 14, 1928 is the only large shallow shock far inland from the South American coast. A depth in excess of 60 kilometers would not conflict with the instrumental data, but is quite unlikely. This shock was destructive in the interior of Peru. Historically, several shocks are known to have been very violent far from the coast in Peru and Ecuador, without the wide area of perceptibility characteristic of intermediate earthquakes. Consequently, this region though only about 300 km. from the sea, may be considered as an exception to the general rule that shallow South American shocks are coastal. Naturally such a rule must exclude superficial volcanic shocks, and also the minor crustal adjustments near the surface which take place in all parts of the world. The shallow shocks of the Mendoza district are discussed below.

The shock of March 18, 1931 has been plotted at the epicenter assigned in the International Summary, about 90 kilometers from Santiago, and very close to Valparaiso. Yet this shock passed almost unnoticed in Chile, except for the remarkable instrumental records. (*See* Bobillier, 1933.) The Santiago seismograms of aftershocks indicate a distance of somewhat more than 200 km. Both at Santiago and at distant stations, such as Pasadena, this shock was notable for the large size of the surface waves compared with the direct bodily waves. All this points to an unusually

shallow focus, probably located farther west, off the coast opposite San Antonio where the shock was felt by a few persons.

Of the smaller shallow shocks that of May 22, 1936 is in the province of

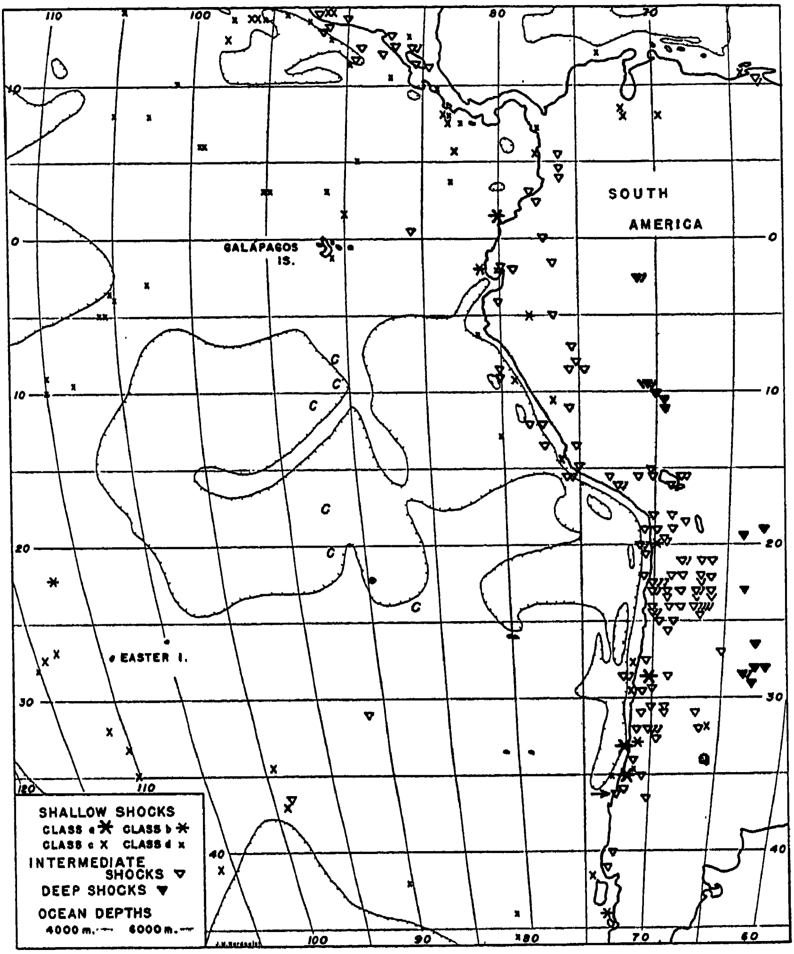

FIGURE 4.—*Map of epicenters, South America and adjacent Pacific*
Arrow indicates shock of 1939, January 25. Letter "C" indicates continental structure

San Luis, Argentina, considerably east of Mendoza. It is the only well-established epicenter which confirms the conclusion, strongly suggested by the history of the region, that shallow shocks occur here in a limited area east of the Andes. Since instances of intermediate focus are known here the mere historical fact of frequent reports of shocks in Mendoza and surrounding provinces is no proof of shallow activity. However, such destructive shocks as the Mendoza earthquake of 1861 cannot have origi-

nated at any such depth as 200 km. The earthquake of May 30, 1929, destructive in southern Mendoza, was probably shallow.

Few, if any, epicenters are found associated with the oceanic deeps off the South American coast. This somewhat modifies the frequently expressed opinion that the destructive seismic sea waves of this coast are due to submarine faulting. A sea wave followed the earthquake of 1922, which had its epicenter on land; the same is probably true of the great earthquake and wave of 1877, so that the mechanics of generation of the sea wave must be of a different character. (*See* Gutenberg, 1939.)

TABLE 7.—*Additional earthquake epicenters in the Southern Antillean region*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1928, Oct. 17	15:19:35	53 S.	54 W.	C	c
1929, Dec. 6	16:46:43	53½ S.	29 W.	C	c
1928, May 15	05:43:45	54 S.	23 W.	C	c
1923, May 1	10:36:18	55 S.	24 W.	C	c
1925, Jan. 21	18:11:10	56 S.	25 W.	C	c
1929, April 13	21:05:59	55 S.	24 W.	C	d
1921, Sept. 13	02:36:44	55 S.	29 W.	C	b
1929, March 28	20:17:57	55 S.	27½ W.	B	c
1930, March 30	08:26:10	54½ S.	27½ W.	A	c
1930, July 13	01:12:22	56 S.	67 W.	C	d
1929, Oct. 21	10:33:38	59 S.	26 W.	C	c
1926, March 21	14:19:12	61 S.	25 W.	C	b
1930, Feb. 18	01:52:48	60 S.	25 W.	C	c
1928, Dec. 27	04:46:10	61 S.	55 W.	C	c
1938, Jan. 24	10:31:44	61 S.	38 W.	B	b
1937, Sept. 17	09:30:41	56½ S.	25 W.	C	c
1937, Oct. 7	07:51:45	59½ S.	53 W.	C	c
1936, Jan. 14	05:36:27	60 S.	22½ W.	B	c
1938, April 2	06:02:00	59½ S.	58 W.	C	c

No shock has been found south of 44½°. Historical information bearing on this is of course very limited; however, a strong shock occurred in 1879 near the Strait of Magellan. (*See* Sieberg, 1932a, p. 986.) This single case is not sufficient to settle the question of connecting the Pacific belt of activity directly with that of the region discussed next.

SOUTHERN ANTILLES

This is the name applied by Suess to the island arc connecting the Antarctic with South America; it includes the South Shetlands, South Orkneys, South Sandwich Islands and South Georgia. The Falkland Islands lie farther north and are geologically different.

The analogy with the West Indies is structural as well as geographical; there is an oceanic deep on the outside of the arc, and active volcanism in the South Sandwich group. The general correspondence extends, with some qualification, to the seismic activity.

Epicenters were occasionally located in this region during the earliest period of instrumental seismology; but the matter escaped general notice until it was discussed by Tams (1927a; 1930a). These shocks are very distant from all but a few seismological stations; consequently the epicenters are less accurate than for most other important seismic areas, and it is not possible to work with any but large shocks. The seismicity as a whole is high, decidedly greater than that of the West Indies. All located epicenters, including those of some intermediate shocks, are plotted on the south polar chart (Fig. 5).

Historical and macroseismic data are very scanty and of little significance. The distribution of known epicenters suggests a closed ring rather than a loop, as the activity does not extend into the Antarctic, and is not clearly connected with that of western South America.

Shocks are most frequent near the South Sandwich Islands and the deep east of them; some of these are large, and one (that of June 27, 1929) is on the list of great shocks (Table 5). Most of the intermediate shocks are in this part of the arc.

The epicenters farther east, and near Bouvet Island possibly indicate a connection with the seismic belt of the Indian Ocean, to be discussed in later sections.

SOUTHEASTERN OCEANIC BRANCH

Seismograms, chiefly at the stations in the Americas, show that a belt of moderate seismic activity runs near the center of the Easter Island Ridge (Fig. 4). A search was made for authentic epicenters in the southeastern Pacific Ocean, in which every adequately recorded shock west of the South American coast was investigated. The large majority of these epicenters were found to lie along a comparatively narrow belt.

The activity is relatively mild, and large shocks are infrequent, so that our knowledge of the seismicity is necessarily imperfect. That the principal belt is an outlying branch of the circum-Pacific zone is a natural hypothesis substantiated in a certain measure by the occasional occurrence of shocks at intermediate depth, thus distinguishing it from the otherwise similar active belts in the Atlantic and Indian Oceans. However, the manner of this supposed branching is difficult to derive from the comparatively few mapped epicenters. Those plotted on the southwestern part of Figure 3 should also be noted here. The most plausible suggestion is that the branching takes place in Mexico, and that an active zone extends southward from Oaxaca past the Galapagos Islands. The few available

epicenters in the triangular area lying between the Galapagos Islands and the coasts of Central America and Colombia suggest an extensive unstable area of complicated character, the details of which are at present inaccessible.

TABLE 8.—*Additional earthquake epicenters in the Pacific off South America*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1928, Dec. 5	11:04:32	3 N.	95 W.	C	d
1928, Dec. 26	21:32:52	6 N.	99 W.	B	d
1927, Nov. 19	06:51:00	10 N.	101 W.	C	d
1930, Jan. 17	16:54:30	8 N.	105 W.	C	d
1926, June 25	03:36:52	28 S.	115 W.	C	d
1925, Dec. 19	16:09:30	32 S.	111 W.	B	c
1929, July 14	08:58:00	33 S.	110 W.	C	c
1929, May 28	04:49:15	33 S.	110 W.	C	c
1920, March 20	18:31:15	35 S.	110 W.	C	c
1927, March 12	18:44:32	41 S.	106 W.	C	c
1930, June 22	18:24:40	44 S.	81 W.	C	d
1936, March 5	06:05:58	9½ S.	108 W.	C	d
1936, Aug. 26	21:19:32	5 S.	106 W.	C	d
1935, Sept. 15	14:09:00	27 S.	113 W.	A	c
1937, May 24	00:40:32	3 N.	95 W.	C	d
1937, Aug. 24	20:13:23	5 N.	89 W.	B	d
1935, June 11	21:55:55	3½ N.	83 W.	C	d
1934, Feb. 20	03:18:45	5 S.	106 W.	C	d
1934, April 9	15:29:23	34½ S.	99½ W.	B	c
1937, Oct. 11	21:23.0	42 S.	90 W.	C?	d
1937, Sept. 15	19:30:05	10 S.	110 W.	C?	d
1937, Nov. 9	10:21:40	36½ S.	97 W.	C	c
1938, Jan. 13	22:44:25	27 S.	116 W.	C	d
1940, Jan. 2	11:07:14	28½ S.	113 W.	C	c
1938, Feb. 4	10:27:21	3 N.	91 W.	C	d
1938, Oct. 10	02:56:23	3½ S.	105½ W.	B	d
1939, July 23	15:07:24	9 S.	110 W.	C	d
1939, Feb. 28	01:17:00	7 N.	103 W.	C	d

Three intermediate shocks are east of the principal belt; one of them, however, occurs together with shallow shocks along a line extending from the region south of Easter Island to the coast of South America. The location of epicenters in this part of the world is difficult, and less accurate epicenters have been mapped here than in most other regions. Comparison of Figures 4 and 5 will show that the Easter Island Ridge, with its accompanying seismic belt, appears to divide into a southeastern and southwestern branch, with deep basins lying between them and the Antarctic continent. Our knowledge of oceanic depths in this part of the world

is still so fragmentary that any attempt to correlate seismicity with bottom contours is somewhat hazardous. Contours shown in Figures 4 and 5 are taken partly from Vaughan, *et al.* (1940) and partly from several charts supplied by the U. S. Hydrographic Office, particularly their Nos. 5411 and 5412. The Hydrographic Office has given the authors prompt and helpful response to inquiries.

Seismograms written at Huancayo for many shocks of this group show a large reflected longitudinal wave (PP); the distances from these epicenters to the station are such that these large amplitudes are evidence of a crustal structure of continental type at the points of reflection. Three instances were noted, and one seismogram was reproduced, in the paper in which this criterion was first discussed (Gutenberg and Richter, 1935). The present investigation adds three more shocks large enough for the purpose; it can now be stated that all of the six larger shocks on and near the Easter Island Ridge south of the equator, as recorded at Huancayo, show clear evidence of continental structure at the points of reflection of PP. These points, which are midway from the station to the corresponding epicenters, are indicated by the letter C on Figure 4. Their dates are: November 2, 1932; February 30 and April 9, 1934; September 15, 1935; March 5 and August 26, 1936. On the other hand, the same type of evidence establishes Pacific structure (1) north of the Galapagos Islands, from seismograms of Chilean earthquakes at Pasadena; and (2) just west of the Easter Island Ridge, near 43° S., 120° W., from a Chilean earthquake as recorded at Wellington (New Zealand). The Easter Island Ridge appears to be the southeastern boundary of the major Pacific basin; but large isolated areas of Pacific structure may exist outside this boundary.

PACIFIC ANTARCTIC

Additional data on submarine contours for the following discussion and for Figure 5 have been taken from the results of the second Byrd expedition, as reported by Roos (1937). The course of the 4000-meter isobath is largely hypothetical. It appears probable that the Easter Island Ridge continues southwestward as indicated, although its summit may descend below the 4000-meter level. On this continuation eight epicenters are mapped:

1937, Nov. 23	13:52:8	44° S.	115° W.
1930, June 15	21:08:2	46° S.	116° W.
1933, April 19	01:45:33	51° S.	116½° W.
1932, March 10	05:17:52	54° S.	135° W.
1940, Jan. 20	09:58:0	55° S.	133° W.
1937, Aug. 13	11:47:38	57° S.	131° W.
1930, Aug. 2	16:09:05	57° S.	135° W.
1938, Sept. 5	14:42:32	55° S.	152° W.

All these shocks are of magnitude class *c*. This is the most difficult of all active areas for the location of epicenters, and any of those mapped may

be in error by 5° or more. Rudolph (1895) reports a very clear case of a shock felt on shipboard in 1884 at 54° 57′ S., 128° 34′ W.

There is unfortunately no seismic evidence bearing on the moot question of a structure connecting the South Antillean arc across Antarctica with

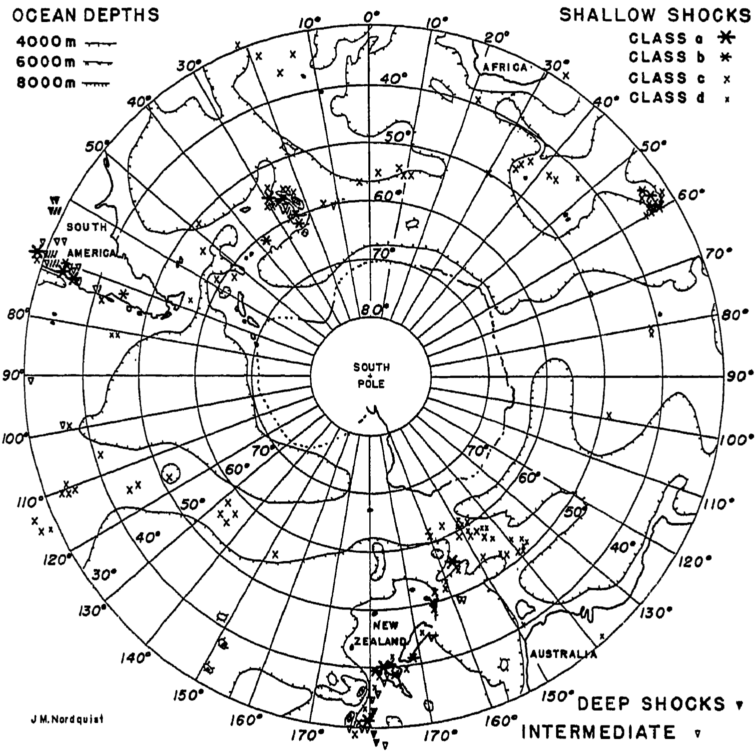

FIGURE 5.—*Map of epicenters south of 30° S. Lat.*

New Zealand. Recent teleseismic observations provide no data indicating shocks either on the Antarctic continent itself, or in any more northerly locality that might fall in the gap between the shocks just listed and those to be discussed under the next head. Presumably the boundary of the major Pacific basin continues southwestward along the trend of the Easter Island Ridge.

The occasionally cited seismographic records obtained by the Scott expedition add very little to our knowledge. The results are published in a summary report by Milne (1905). Instruments were installed near 77° 51′ S., 166° 45′ E., and were operated for several months in 1902–1903. One hundred and thirty-six shocks were recorded, none of which were felt.

Twenty-seven were identified as originating in distant parts of the world; 73 others were located between the station and New Zealand, by using records at Wellington, Christchurch, and Perth. Locations for the remainder are not mentioned; but considering the characteristics of the instruments then in use, it is not likely that trustworthy conclusions could be drawn from these seismograms. It is quite possible that no truly Antarctic shocks were recorded, and that the most southerly of those noted belonged to the group now to be discussed.

MACQUARIE ISLAND LOOP

Seismograms, and occasional reports of shocks felt on shipboard, long ago established the occurrence of earthquakes southwest of New Zealand, between 50° and 60° S. Earlier writers took for granted that this indicated an active belt extending, without much change in direction, from New Zealand into the Antarctic. The better recorded shocks of this group were investigated carefully before plotting on a large-scale map, when the unexpected result appeared that the alignment has the character of an active loop open to the east (Fig. 5). This adds a third member to the group of loops connected with the circum-Pacific belt, quite comparable to the Caribbean and South Antillean loops, and indicates the presence of a hitherto unknown structure of geological importance.

The seismic loop is rather narrow; this suggests that the epicenters are on the interior of the supposed structural loop. Deep soundings have been obtained at a few points in the interior. The apex of the loop is near 50° S. 140° E., not far from the point where some charts show Royal Company Islands.[3]

The degree of seismicity is closely comparable with that of the South Antilles, the greater number of located epicenters being due to the proximity of the stations in Australia and New Zealand, which makes it possible to work with smaller shocks than in the South Atlantic. On the north limb of the loop, not far from Macquarie Island, is the great shock of June 26, 1924 (Table 5).

Intermediate shocks, which might be expected on analogy with the other Pacific loops, have not been found here. However, it would be difficult to distinguish a shock at a depth of 100 km. from a shallow shock in this area; and intermediate shocks have been identified a little farther north, between the loop and New Zealand. Doubtless the Macquarie Island loop is associated with a structure of Pacific type; whether it forms part of the boundary of the Pacific basin cannot be determined at present.

[3] According to information kindly furnished by Prof. W. H. Hobbs and by Colonel L. A. Martin of the Library of Congress, these islands were reported seen before 1814 and were reported not found in 1820 and on several occasions since. The possibility of temporary volcanic islands should not be overlooked.

NEW ZEALAND AND THE TONGA SALIENT

The shocks next to be discussed are mapped on Figures 5 and 6. A belt of activity at shallow depth extends from Macquarie Island northeastward past New Zealand nearly to Samoa, deviating very little from a great circle.

TABLE 9.—*Additional earthquake epicenters southeast of Australia*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, Dec. 28	01:22:53	40 S.	149 E.	C	d
1929, Jan. 21	04:55:35	50 S.	136 E.	C	d
1929, Dec. 31	04:10:20	51 S.	138 E.	C	d
1927, June 14	17:16:55	50 S.	140 E.	B	c
1927, Dec. 31	23:13:23	51 S.	140 E.	C	d
1926, July 25	04:52:40	51 S.	146 E.	C	d
1921, Jan. 7	02:51:24	51 S.	140 E.	C	d
1927, Sept. 7	19:57:05	56 S.	148 E.	C	c
1929, Dec. 28	11:28:24	56½ S.	143 E.	C	d
1929, Dec. 16	00:45:31	55 S.	156 E.	C	d
1928, Feb. 29	21:57:00	58½ S.	148 E.	C	c
1925, Aug. 14	04:08:38	59 S.	151 E.	C	c
1930, Dec. 13	02:35:32	60 S.	150 E.	C	d
1930, Sept. 14	03:01:05	60 S.	148 E.	C	c
1929, May 22	20:06:15	62 S.	155 E.	C	c
1937, July 19	03:10:12	53 S.	145 E.	C	d
1938, Oct. 9	16:36:40	61 S.	160 E.	C	c
1936, Feb. 22	15:31:54	49½ S.	164 E.	B	c
1936, Feb. 22	19:22:40	50 S.	164 E.	C	c
1939, Sept. 7	19:20:14	50½ S.	164 E.	C	d
1939, Sept. 20	07:28:20	50 S.	164 E.	C	d
1939, Nov. 10	16:49:40	53 S.	160 E.	C	d
1940, Oct. 1	21:38:22	61 S.	160 E.	C	c
1940, Aug. 8	14:08:23	57½ S.	147 E.	C	c
1940, March 14	18:22:35	56 S.	145 E.	B	c

Seismicity in this belt is not high, but shocks of all magnitudes up to the very largest occur. Northeast of New Zealand these shallow shocks fall between the islands of the Kermadec and Tonga groups on the west, and the oceanic troughs of the same names on the east. No epicenters can be verified to the east of these troughs. O. Hecker observed gravity anomalies of about +200 milligals on the Tonga Plateau, and −200 milligals over the Tonga Deep (Heiskanen, 1936, p. 932).

The belt of shallow shocks follows the andesite line, and turns westward with it between Samoa and the northern Tonga Islands, passing north of the Fiji Islands. It thus follows the boundary of the northeastern angle of the Australasian continental area, here referred to as the Tonga salient.

The north side of the salient is much less active than the east side, and only the few epicenters mapped in this part of Figure 6 can be verified. This is a result of a careful search of the International Summary and recent station bulletins. Particular attention was given to shocks indicated as outside the Tonga salient, as these would fall into the otherwise inactive Pacific basin; but only a few shocks near Samoa could be verified, the remainder being small, doubtful, or clearly in error. The interior of the salient had already been thoroughly canvassed in a search for deep-focus earthquakes.

Figures 5 and 6 show only selected shallow shocks, while every intermediate or deep shock located in the region is mapped. The comparative numbers of the two types of shocks shown are consequently without much statistical significance, apart from the evident fact that it has been possible to locate an exceptionally large number of deep shocks here.

Closely associated with the belt of shallow earthquakes are a number of shocks at depths near 100 km. Most of these are along a northeast-southwest belt nearly parallel to the belt of shallow shocks, but farther from the Pacific. A few occur between Samoa and the most northeasterly shallow shocks, and are consequently the only shocks found immediately external to the Tonga salient.

In this area distinction between intermediate and shallow shocks is difficult only for small shocks or for those of early date. In New Zealand shallow shocks predominate. Not only the data of the local stations, but also macroseismic observations, bear on this point. Faulting at the surface was observed in 1855, 1888, 1929, and probably on other occasions, so that at least these large shocks must have had a shallow origin. The few New Zealand shocks indicated as intermediate are distinguished by a wider spacing of the isoseismals, combined with lower epicentral intensity, than is the case for shallow shocks of about the same magnitude. From the Kermadec Islands to Samoa the instrumental statistics indicate that shallow shocks are relatively, perhaps absolutely, less frequent.

West of the main belt of shallow and intermediate shocks, but trending more nearly north and south, is a somewhat irregular zone which is the most active source of very deep shocks in the world. At least 25 shocks at depths of 500 km. or more have been located here; and there are not a few others for which the depth and general region are known, but which have not been recorded sufficiently well for a close determination of the epicenter. The depths are greatest near 21° S., 180°, where the hypocenters range down to nearly 700 km. below the surface. Some of these are earthquakes of very large magnitude; that of May 26, 1932 (No. 52) wrote enormous amplitudes comparable with those of the great shallow shocks of Table 5, for all but the surface waves. (*See* Brunner, 1938.) No shock of this group is found south of 33°.

East and north of these very deep shocks are a number at depths ranging from about 200 to about 400 km. They appear to form a fringe about the region of very deep shocks. Some shocks to the northeast, with depths near 300 km., are geographically better associated with the shallow and intermediate group than with the deep shocks; this and similar conditions in South America have led to our including shocks down to this level in the intermediate range.

Several epicenters added between the South Island and Macquarie Island are given in Table 9. North of Fiji the following have been added:

1932, Feb. 16	13:48:50	15° S.	180°	A	b
1923, July 12	03:15:45	14½° S.	180°	C	c
1938, March 25	15:49:26	14½° S.	179° E.	C	c

and west of Fiji:

1930, June 5	11:42:48	16½° S.	174° E.	B	b
1933, Sept. 22	11:37:36	16½° S.	174½° E.	A	c

The isolated shallow shock at 18° S. 179½° W. occurred on March 8, 1932; it may possibly be as deep as 80 km.

The New Zealand observers have reported an abundance of additional material in mimeographed bulletins issued from Wellington, with annual summaries, included in the Annual Report of the Department of Scientific and Industrial Research, and also issued as separate bulletins by the Dominion Observatory. Many epicenters determined at Wellington refer to small earthquakes; now, experience in California and elsewhere shows that the small shocks of active regions frequently occur along minor structures, and thus tend to obscure the pattern of major activity. The writers' own experience has also emphasized the unavoidable risk of errors of interpretation in dealing with shocks recorded only at a few local stations. These principles have led to the rejection of many interesting shocks not well recorded outside of New Zealand, among them several shocks, located by the workers at Wellington as east and southeast of the North Island frequently with attribution of intermediate focal depth.

Most New Zealand epicenters fall along two principal fault systems which traverse the islands longitudinally. Of these one, which includes a number of distinct faults, runs not far inland from the Pacific coasts of the two main islands. Historical data are not extensive, owing to the short time during which these islands have been settled by white men. The great earthquakes of 1848 and 1855 were clearly associated with the fault system just mentioned, and the shocks of 1931 and 1934 on our map belong to it. The second principal active line passes more centrally through the North Island, and west of the center of the South Island. Its northern segment passes through the volcanic areas of Lake Taupo, Rotorua, and White Island; intermediate shocks occur on this line, in harmony

with the relation found in other regions. The New Zealand seismologists recognize other active lines, all with the same general longitudinal trend.

The southern half of the South Island is comparatively quiet; this is supported by the meager historical data, except for the fiord region at the

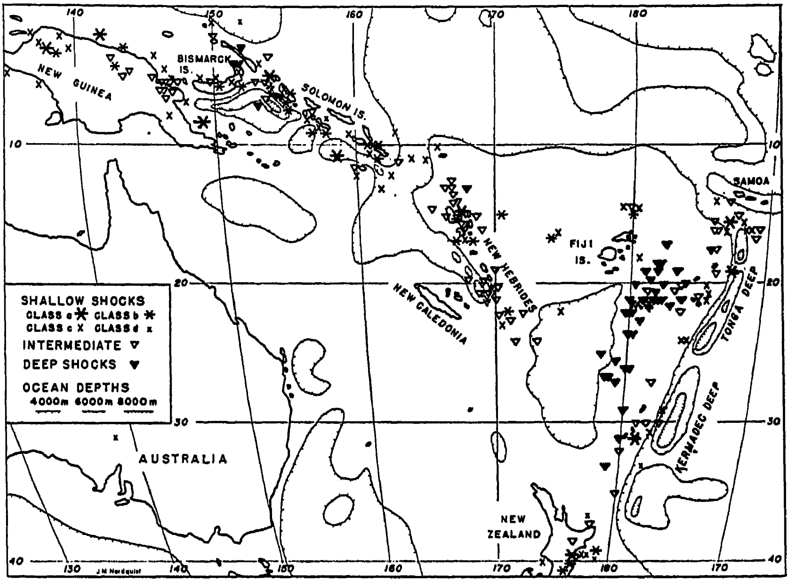

FIGURE 6.—*Map of epicenters, New Zealand to New Guinea*

southwest, which is near the epicenter of the large intermediate shock (depth 70 km.) of December 16, 1938.

The Kermadec, Tonga and Samoan Islands have a history of strong shocks.

NEW HEBRIDES TO NEW GUINEA

The extremely active seismic belt of the Melanesian islands (Fig. 6) follows a structure which in its western course parallels the margin of the Australasian continental area, as indicated by the andesite line. Farther east it trends southeastward, departing from the andesite line as usually drawn, so that it apparently passes from a marginal to an interior structure.

The majority of the shocks are shallow or in the shallower part of the intermediate range. It has not been necessary to list or map additional shocks, as investigation revealed no verifiable epicenters in areas not already well represented, except for: 1938, April 20, 06:27:05, 22° S. 175° E., A c.

Many shocks in this region are of large magnitude. Of those mapped on Figure 6, six are from Table 5 (1906, 1914, 1919, 1934, 1935, and 1939). Except for a few very recent or unusually well-recorded shocks epicenters in this region may be in error by 2 degrees or more. In many cases this might seriously affect the terms of a general description. Until the last few years, shocks in this region have been notoriously difficult to locate with precision, owing to a peculiar distribution of the nearer stations in distance and azimuth. This has been improved by the readings of the station at Brisbane (Queensland), which began recording in 1937.

In the New Hebrides some past difficulties were due to the depth of focus. There is doubt whether any shocks of shallow focal depth occur in this part of the region, unless they are of small magnitude. So many of those at first supposed to be shallow proved to have focal depths of the order of 100 km., that adequately recorded shocks near the New Hebrides were very carefully scrutinized. One result was the omission from Table 5 of an earthquake included in our former table of great shocks, and assigned magnitude $7\frac{3}{4}$ from the reported amplitudes of surface waves. This shock occurred on November 9, 1910, at $06^h\,02.2^m$, near 18° S. 168° E. The evidence for intermediate depth is not completely satisfactory, and does not allow any depth to be specified. The great shock in the New Hebrides on July 18, 1934, is mapped as a shallow earthquake (Table 5). The seismograms of this shock are large, and suggest the occurrence of a complicated shock or series of shocks; possibly it belongs to the upper levels of the intermediate range. A smaller shallow shock is mapped at 22°.8, S. 170°.5 E.; this occurred on April 12, 1931. The appearance of the seismograms, and the recorded times, give none of the characteristic evidence of depth. This is confirmed by the large shock near by on March 16, 1928 (Table 4). The shock at 15° S. $170\frac{1}{2}$° E. (Table 4) belongs to the same marginal group as the shocks north and west of the Fiji Islands. Two other shallow shocks, mapped in the extreme north of the New Hebrides area, seem well established. The deep shock at 13° S. 168° E. is of exceptional importance. This is No. 81*M*. listed in Table 1. The focus is certainly below the 300-kilometer level taken as dividing deep from intermediate shocks and the epicenter, though not very precise, is well to the northeast of the islands. Previously only shallow and intermediate shocks were known between the western Solomon Islands and the Tonga salient.

In the Solomon Islands there is no question about the frequent occurrence of shallow shocks. The exceptionally high activity of these islands is well brought out on the world map (Fig. 2). Many of these earthquakes generate enormous surface waves of the Love type, with periods of more than 1 minute and amplitudes measured in centimeters even at distant stations (*G* waves). Those of the earthquake of October 3, 1931,

are discussed in detail in a previous paper (Gutenberg and Richter, 1934), where they are tentatively attributed to the displacement of large crustal blocks.

Oceanic troughs, and most of the active epicenters, lie to the south of the Solomon Islands and New Hebrides, or on the side away from the Pacific basin. This is contrary to what is found on the east face of the Tonga salient, on the coast of Japan, and elsewhere on the Pacific boundary where the relation of focal depth to epicentral position also appears to be opposite to that in the present region. Intermediate shocks in the Solomon Islands are usually at depths near 100 km. West of the northwestern island of the group (Bougainville Island) are three shocks at depths near 400 km. It is natural to associate these with shocks at nearly the same depth in the Bismarck Islands northwest of them.

The Bismarck Islands clearly indicate a change in the seismic belts as well as in the geographical and geological relations. The northeastern island, New Ireland (Neu-Mecklenburg) is on the general line of the Solomon Islands, and the activity pattern is fairly similar, including the deep shocks just mentioned. It has been suggested that the shocks near New Ireland, including an additional shock at 1° S. 152° E. (1938, Feb. 7, 1:19:04, B d) are on an extension of the seismic belt following the Marianne Islands. However no shocks, deep or shallow, have been found in the intervening gap across the Caroline Islands. Our data are still manifestly incomplete, especially for deep shocks.

The few shocks associated with the larger island of New Britain (Neu-Pommern), appear on the map as if associated with the trough on the convex side of the curved island structure. These, with the shocks along the north coast of New Guinea follow a volcanic belt (Fisher, 1940).

CAROLINE ISLANDS

The passage of a branch of the circum-Pacific belt from New Guinea to the western Caroline Islands is a little uncertain, and it is not yet possible finally to reject the older view which prolonged the extremely active belt of the Melanesian islands directly into the equally active region of the East Indies. The reasons for this rejection are largely based on the structure of the complicated region between Halmaheira, Ceram and New Guinea, across which such a connection must be drawn. That almost inactive and extremely active segments follow one another in the same branch is no difficulty; several instances of the sort have been given in following round the Pacific.

Undoubtedly the boundary of the Pacific basin runs northward in this region, and the Philippine basin northwest of the Caroline Islands covers a region predominantly of continental type, perhaps comparable with that in the southeast Pacific between South America and the Easter Island

TABLE 10.—*Additional earthquake epicenters in the Marianne and Caroline Islands*

Date	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1930, Oct. 3	18:09:10	2 N.	135½ E.	C−	c
1928, Nov. 15	02:32:18	2 N.	133 E.	C	d
1930, March 30	00:26:45	11 N.	141 E.	B	c
1929, Dec. 31	01:03:57	11 N.	141 E.	B+	c
1930, March 31	23:44:58	12 N.	144 E.	C−	c
1925, July 17	03:13:53	12 N.	141½ E.	C	c
1925, July 17	22:31:04	14 N.	142 E.	C−	c
1928, Feb. 13	05:33:37	11 N.	141 E.	C	c
1929, Jan. 17	22:28:42	12 N.	144 E.	B	c
1929, May 1	07:38:41	14 N.	147 E.	C	c
1928, Oct. 10	20:36:30	13 N.	146 E.	C	d
1927, July 17	08:48:33	13 N.	141 E.	C	c
1924, Jan. 30	04:47:43	13 N.	144 E.	C	c
1921, Feb. 10	23:53:45	18 N.	148 E.	C	d
1930, Oct. 28	21:10:22	18½ N.	147 E.	A	c
1930, Oct. 29	12:29:36	19 N.	148 E.	C	d
1920, Jan. 12	13:39:58	23 N.	144 E.	C	d
1926, April 22	23:47:52	23 N.	145 E.	C	c
1929, March 9	02:11:51	24½ N.	142½ E.	B	c
1927, Feb. 22	19:54:16	28 N.	144 E.	C	c
1924, April 25	18:04:59	27½ N.	142 E.	C	d
1928, Sept. 19	08:15:48	29 N.	142 E.	C	c
1929, March 14	18:37:16	28 N.	139½ E.	C	d
1928, Jan. 26	18:50:39	29 N.	143 E.	C	c
1925, May 20	11:04:48	30½ N.	142½ E.	B	c
1925, May 22	09:40:10	30½ N.	142 E.	B	c
1927, April 27	19:16:17	30½ N.	142 E.	B	c
1927, May 16	12:01:05	30 N.	142 E.	B	c
1927, May 18	09:25:10	30½ N.	142 E.	C	d
1927, May 20	22:09:18	30½ N.	142 E.	C	d
1924, June 22	13:23:53	31 N.	143 E.	C	c
1927, Oct. 31	13:25:10	29 N.	142 E.	C	d
1926, May 7	06:11:28	31½ N.	141 E.	C	c
1921, Sept. 3	08:58:00	33½ N.	143 E.	C	c
1926, June 21	08:48:52	30 N.	142½ E.	C	c
1927, Oct. 24	19:05:32	33 N.	143 E.	C	d
1927, Oct. 28	15:22:56	33½ N.	143 E.	C	c
1927, Oct. 8	12:26:10	34 N.	143 E.	C	c
1929, March 18	23:21:02	38½ N.	143½ E.	B	c
1924, Aug. 6	14:22:30	38 N.	141 E.	C	c
1935, Sept. 9	06:17:33	7 N.	140 E.	B	c
1936, April 12	20:51:00	8 N.	137½ E.	A	b

Ridge. The boundary is indicated by the andesite line, which certainly runs north of Melanesia, and east of the Marianne Islands as far south as

Guam. The western Caroline Islands, including Yap, are andesitic; the eastern Carolines are islands of Pacific type, so that the andesite line and the Pacific boundary must run between the two groups. Whether the andesite line is continued southwesterly to a point north of western New Guinea, as drawn by Born (1933, p. 766), or more nearly south, as drawn by Chubb (1934), seems to be rather arbitrary, as there appear to be no data bearing on the point. The seismological evidence, as will now appear, slightly favors Born's interpretation.

Shocks in this region are relatively infrequent. Figure 7 shows the result of investigating every shock indicated in the International Summary or recent station bulletins as occurring in or south of the Caroline Islands. All verified epicenters in this area are shown,—except that near Guam, where the activity increases (Repetti, 1939) minor shocks are omitted.

The critically important area shows only shallow earthquakes, although deeper shocks occur both in the Melanesian belt and in the Marianne Islands from Guam north. The activity is very slight on the whole, increasing in the western Carolines between Yap and Guam. One great shock (that of 1911, Table 5) is shown near Yap. A shock off the west point of New Guinea (August 10, 1927) is from Table 4.

Fortunately, two epicenters have been verified in the otherwise complete interruption of the active line between New Guinea and Yap. One of these (November 15, 1928) is directly in the suggested line, at 2° N. 133° E. It is fairly well recorded; the data, in good agreement, are supported by those of another shock from the same source 5 hours later. The shock of October 3, 1930, at 2° N. 135½° E., is not so good a case; but the data place it definitely east of the 1928 shock. At 7° N. 140° E. is an epicenter clearly southeast of Yap, in a position similar to that of the 1930 shock. This one (September 1, 1935) is well recorded, and the location is good. All three epicenters together support the hypothesis that a fairly wide active belt lies just southeast of the line from Western New Guinea to Yap.

MARIANNE ISLANDS TO JAPAN AND KAMCHATKA

The earthquakes of Japan, included partly here and partly under the next head, are difficult to summarize in a general discussion. The unusual wealth of material naturally results in making the treatment of this region somewhat more detailed than that of other areas of equal importance.

In certain local areas seismicity reaches a peak hardly exceeded elsewhere. Many of the shocks are large, and could be located even without the help of the numerous seismological stations of Japan. On the world map (Fig. 2) shocks of 1931–1933 which should have been mapped were so numerous that it was not possible to indicate them separately. In spite of their larger scale, the same difficulty arose at some points on Figures 7 and 8.

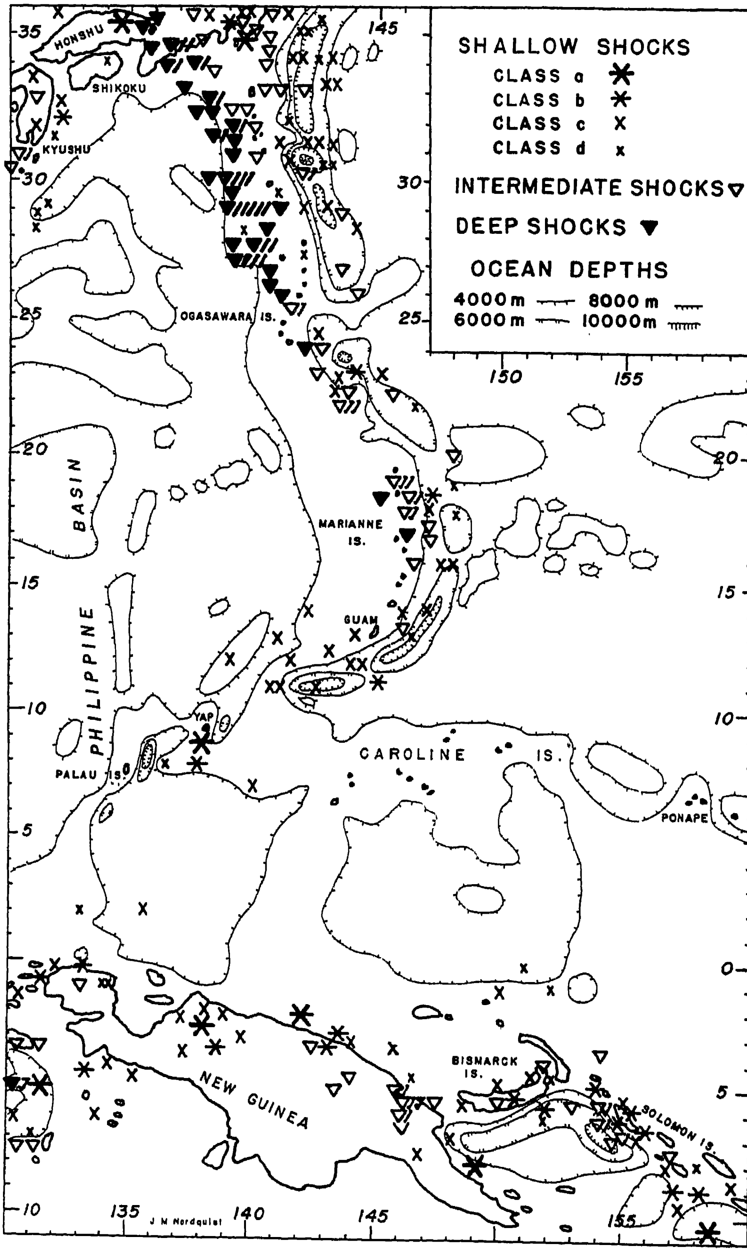

FIGURE 7.—*Map of epicenters, New Guinea to Japan*
Including the Caroline and Marianne islands

Deep and intermediate shocks are very numerous. Most of the shocks in the list by Wadati (1940) are included, but intermediate earthquakes in

this area since 1933 have been investigated only when large or well recorded, or when the epicenter appeared to be unusual.

Table 11 contains additional shocks in the Kurile Islands, resulting from examination and revision of epicenters located in the International Summary in the Pacific basin area. As in other regions, unusual epicenters

TABLE 11.—*Additional earthquake epicenters east of Japan and the Kurile Islands*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, March 14	14:14:55	40 N.	146 E.	C	d
1930, August 21	15:05:20	44 N.	148 E.	C	d
1929, July 25	15:07:54	47 N.	153 E.	C	c
1925, Jan. 31	17:00:40	45 N	149 E.	C	d
1921, Jan. 2	07:06:40	43½ N.	150 E.	C	c
1922, May 5	00:18:45	47 N.	151 E.	C	c
1930, April 24	00:23:45	47 N.	150 E.	C	c

have all been revised; a number of misinterpreted deep-focus shocks have been found in this way.

Historical data for Japan are more significant than for most seismic areas, since the records kept for centuries include many shocks of great magnitude, which are important and useful in studying the relation of present activity to that in the past. For the larger facts of this kind *see* Imamura (1937, especially p. 144–150).

Extending north from Guam are two seismic belts, geographically related in a way which apparently is not duplicated anywhere else. There is an eastern belt of shallow and intermediate earthquakes, and a western belt of deep shocks, which diverge as they go northward, take entirely different courses, and approach once more near Kamchatka. They will now be discussed separately.

From Guam the belt of shallow and intermediate earthquakes follows a series of island groups, where the nomenclature is very unsettled. Guam is the most southerly of the Marianne Islands, which for some reason are more commonly referred to as the Marianas, and occasionally by the older name of the Ladrones. North of these are minor islands and groups, among which are those formerly generally referred to as the Bonin Islands, but now more commonly called the Ogasawara-jima. Approaching the mainland of Japan the belt passes still other islands, including Hatidyozima (with many variant spellings[4]) and lastly the group of the Idzu

[4] Such as Fatsijo-shima. The practice of the Japanese themselves, not to mention that of foreigners, in transliterating local names into the Occidental alphabet, is extremely variable; many of the older and more familiar spellings are now little in use. Fujiyama is hardly recognizable as Mount Huzi, and the reader in seismology must learn that Tu and Tsu are the same. The syllables spelled "shima," "sima," "zima," "jima" form the Japanese word for "island."

Shichito. The belt continues along the east coast of Honshu, and by way of the Kurile Islands to Kamchatka.

Between Guam and Honshu the general seismicity is not so high as farther north, and shallow shocks are relatively less frequent, with deep and intermediate shocks constituting a large fraction of those recorded. Some shocks listed as shallow may be at slightly greater depths, about 70 km. The plurality of deeper shocks here is so striking that the International Summary has been searched for shocks along this line; all these, except a few near Guam, have been investigated, and catalogued as shallow or deeper when sufficiently well recorded. The additional shallow shocks of this group are listed in Table 10. The shallow shocks occur east of the island chain, and the intermediate shocks more nearly along the line of the islands, while the belt of deep shocks lies farther west. Thus the shallow shocks are on the edge of the Pacific basin, near the andesite line, and depths increase on recéding from it. In all these respects the seismic conditions are similar to those on the Pacific coast of South America.

The belt of shallow and intermediate shocks reaches Japan proper in the region of Tokyo. Here and in the remainder of its course we encounter the high activity, which reaches a maximum off the east coast of Honshu. Five great shocks, taken from Table 5, appear here; these are in order the Tokyo or Kwanto earthquake of 1923, the Sanriku earthquake of 1933, and the three shocks in the Kurile Islands and Kamchatka in 1918, 1904, and 1923. Some of the intermediate shocks are of great magnitude. On May 1, 1915, at 05:00.0, a shock occurred in the Kurile Islands near 47° N. 155° E. This shock would be assigned magnitude 8 from the reported amplitudes of the surface waves; however, the data suggest intermediate depth, without being sufficient to establish either depth or epicenter accurately, so that the shock does not appear in any of our tables. The earthquake of January 13, 1929, south of Kamchatka (No. 168) was equally large, and had a well-determined depth of 140 km.

The shallow shocks of this group occur chiefly on the outer or Pacific margin of the active belt; many of them are on the western edges of the oceanic troughs off these coasts. An exception is provided by the shocks of the Kwanto district, including Tokyo. Some of these are at depths of about 70 km., but others are certainly shallow.

Most of the intermediate shocks of the entire belt, from Guam to Kamchatka, occur directly under the well-known volcanic band which includes all the smaller islands mentioned and runs inland in eastern Honshu, thence through the Kuriles. Here again the seismic activity follows the inside of the andesite line, which separates it from the inactive Pacific basin. As in some other regions, deep oceanic troughs associated with high seismicity are accompanied by large gravity anomalies (Matuyama, 1936).

A few shocks at depths of 200 km. and more occur inland or in the Japan Sea, far from the main belt of intermediate shocks. These apparently are not associated with the belt of deep shocks discussed below, but suggest an inner belt of intermediate shocks parallel to the main outer belt, somewhat similar to the belt of shocks at about the same depth under the eastern Andes.

The abundant historical data demonstrate the existence of three chief zones of destructive earthquakes, most of which must be at shallow depth. One of these zones is that lying off the Pacific coast of eastern Honshu. Here the larger shocks are destructive on land, and are frequently followed by still more destructive seismic sea waves (tsunamis). An important, but less active, second zone follows the northern and western coast of Honshu, along the Japan Sea. This is represented on Figure 8 by the following shocks:

1933, July 13	07:57:40	42½° N.	138¾° E.	A	c
1933, Sept. 21	03:14:32	37° N.	137° E.	A	c
1933, Oct. 3	18:38:58	37¼° N.	138¾° E.	A	c
1939, May 1	05:58:33	40° N.	139¾° E.	A	c
1940, Aug. 1	15:08:21	44½° N.	139° E.	A	b
1940, Aug. 13	15:36:40	36° N.	132° E.	B	c

and by the Tango earthquake of 1927 (Table 5), which is probably the largest of these shocks during the historical period. This zone is more naturally associated with the western main branch of the Pacific belt. It appears to have secondary branches of its own, which strike southward into eastern Honshu north of Tokyo, and may possibly account for the shocks of the Tokyo region. All shocks of the Japan Sea coast appear to be shallow; for the Tango earthquake there is no doubt of this, since fault displacements occurred at the surface. The same applies to the Mino-Owari earthquake of 1891, which is the outstanding shock of the third chief belt of shallow earthquakes. This belt crosses Honshu near its narrowest point, about Long. 137° E.; Figure 8 shows no shocks associated with it.

The remarkable structure known as the Fossa Magna is a zone of fissuring and volcanic activity extending from the Idzu peninsula through Fujiyama directly across Honshu. Geographically, it is an apparent continuation of the volcanic belt extending from the Marianne Islands to the Idzu group. Earthquake activity near the Fossa Magna is shallow, some of it being clearly superficial and volcanic in origin. Figure 8 shows shocks in the zone only near the coast west of Tokyo, about the Idzu peninsula. There is a marked difference in geology and possibly in the crustal layering on the two sides of the Fossa Magna. The Mino-Owari seismic belt and the transverse belt of deep shocks are far to the west of it.

In the Marianne Islands, deep earthquakes in the restricted sense are

represented by two well-observed shocks at depths of 520 and 570 km. (Nos. 171 and 171f). The continuous belt of deep shocks begins north of the Marianne Islands, in Lat. 24°. Depths range from 300 to over 500 km., with many shocks near 400 km. The belt crosses Honshu west of the

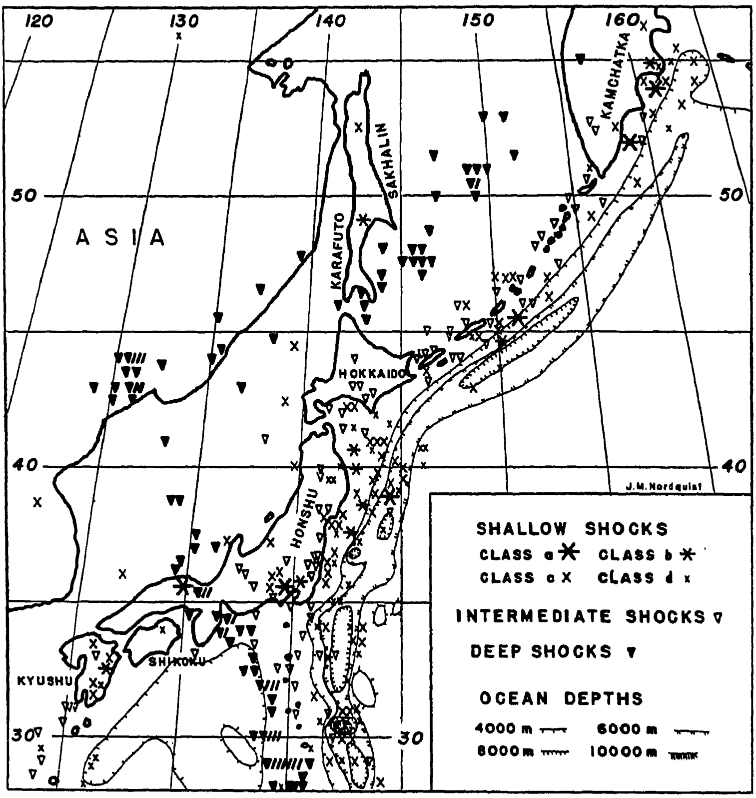

FIGURE 8.—*Map of epicenters, Japan to Kamchatka*

Mino-Owari shallow earthquake zone. Here there have occurred some of the best observed of all deep-focus earthquakes, at depths near 360 km. Several of these shocks have been large enough to record at many distant observatories, at all the chief stations in Japan, and at 10 to 15 local stations within 2 degrees of the epicenter. Just east of these are some of the intermediate shocks already referred to, at depths less than 300 km.; the two sets of epicenters are clearly separated geographically, so that the 300-kilometer level, as originally selected by Wadati, remains the best choice for the separation between intermediate and deep shocks.

The main belt of deep shocks extends across the Japan Sea, although the depths of the very few shocks in that part of its course are hard to deter-

mine accurately. The belt extends past the Asiatic coast into Manchuria, where it ends, or makes a right angle turn, or intersects another similar belt, according to one's preference in interpreting the data. In this Manchurian area shocks at greater depths, down to nearly 600 km., are more frequent. From here the Sôya deep-focus zone of Wadati (1940), trends northeastward. The shocks appear to be actually fewer in number than those of the transverse zone crossing Honshu, although the smaller number of epicenters here is partly due to the greater distance from the stations of central Japan. Some evidence of separation into a northern and a southern line exists. The former at first remains inland, reaching the Asiatic coast at about 140° E.; it should cross Sakhalin near its center, where no epicenters are known at present, and appears to be continued across the Sea of Okhotsk into western Kamchatka, where the map shows the most northerly known deep shock, with a not very well-determined depth near 340 km. (No. 227). The southern line leaves the mainland more directly, and passes near the straits of Sôya between Sakhalin and Hokkaido. Here shocks near 400 km. are fairly frequent; beyond, the line enters the Sea of Okhotsk, where the focal depths of some shocks are below 600 km.; these are the deepest earthquakes in the entire Japanese area.

JAPAN, FORMOSA, AND LUZON

On reaching Kamchatka the circuit about the Pacific is complete; but we have yet to discuss the great western branch of the circum-Pacific belt, diverging from the eastern branch in central Japan, passing by way of the Philippines into the East Indies, and possibly connecting through the Sunda Islands and Burma with the trans-Asiatic zone.

This branch clearly accounts for the shocks along the Japan Sea coast of western Honshu, including the large Hamada earthquake of 1872. Probably it includes the locally strong shocks which are not rare in and near the Inland Sea north of Shikoku, especially near 34° N. 133° E.; one of the largest of these occurred on June 2, 1905.

Most maps of the seismicity of Japan show a submarine active belt including the shocks off the east coast of Honshu, but continuing along the entire Pacific coast of the islands past Shikoku to Kiushiu. Figure 8 does not support this. The absence of epicenters of large shocks between Kiushiu and central Honshu was verified by careful investigation of epicenters in the International Summary between the limits 30° and 35° N., 132° and 136° E. All of these were found to be imperfectly recorded and doubtfully located shocks, or else small shocks near the recording stations. Such local shocks are of no use in studying the seismic belts of Japan, as they occur in the vicinity of every recording station, and many of them are clearly volcanic in origin.

The map shows one intermediate shock in the questioned part of the

Pacific coastal belt, at 33° N. 135½° E. This is the Wakayama earthquake of January 11, 1938 (Minakami, 1938). Incomplete instrumental data on this shock fix the epicenter within about a degree and suggest a depth of about 70 km. This is only tentative; the shock may be shallow.

Over a limited period, the epicenters of even moderately large shocks may fail to indicate an important seismic zone; thus the Mino-Owari transverse belt is not represented on our maps. However, there is reason for supposing the Pacific activity off Shikoku to be different in kind from that farther northeast. Here there are no notable oceanic troughs, and no large gravity anomalies. Nevertheless, some strong shocks are commonly assigned to the hypothetical continuation of the coastal belt. Of these, perhaps the most convincing is the very great earthquake of 1707, which was extremely violent on Shikoku and on the Kii peninsula east of it, and of high intensity in a wide area. This shock was followed by destructive tsunamis which entered the channels on both sides of Shikoku. All this would be quite consistent with an epicenter near that of the 1938 Wakayama shock; but such questions must be left to the Japanese investigators.

West of this problematic region of Shikoku is the unquestionably active island of Kiushiu. From here a fairly continuous seismic belt extends past Formosa to Luzon. Figures 8 and 9 show all known intermediate shocks, and selected shallow shocks. The following shallow shock has been added:

Aug. 28, 1924	23:50:36	33½° N.	131° E.	B	c

This may belong to the Japan Sea coastal belt. A shock near this point on September 25, 1928, is given as shallow by Wadati (1931); records at distant stations suggest a depth of 100 km., so that this shock has not been included in any of our lists. Near-by is shock No. S 29 p (January 23, 1937), doubtfully assigned a depth of 100 km.

The belt from Kiushiu to Luzon shows very uniform seismic characteristics throughout. Shallow shocks occur on the eastern or Pacific side of the belt, with numerous intermediate shocks, chiefly at depths from 100 to 200 km., on the opposite side. Thus the line of intermediate epicenters runs definitely north of the Riu-Kiu Islands, while the shallow shocks are rather to the south of them. Clear exceptions are the shock off the east coast of Formosa (No. 136 *g*, depth 130 km.) and one near the Batan Islands north of Luzon (No. 136, December 21, 1930, depth 170 km.), which is very well located and clearly farther to the east than might be expected. The belt probably does not pass directly from Formosa to Luzon; Repetti (1931b, 1935) draws seismic and structural lines here with a northeast-southwest trend, and this offset or curvature may account for these seemingly anomalous epicenters. No true deep shocks are known from this area.

In addition to shallow and intermediate tectonic earthquakes, Kiushiu is visited by strong volcanic shocks. An important question is raised by the large Kagoshima earthquake of January 12, 1914, which accompanied an eruption of the near-by volcano Sakurajima. This shock had a large area of perceptibility, and sufficient energy to be well registered at European stations. It might be regarded as a purely tectonic shock, and its occurrence during an eruption as fortuitous; but similar instances are known, such as that of 1868 in Hawaii.

Intermediate shock No. 138 p (June 15, 1911), mapped at 29° N. 129° E., was originally in our list of great shallow shocks. It was destructive on the small island of Kikai, over 1 degree from the instrumentally determined epicenter.

Formosa, or Taiwan, is a region of higher activity than the adjacent parts of the seismic belt, exceeding most regions of Japan in frequency and magnitude of the recorded shocks. The two great shocks of 1920 and 1922 are taken from Table 5. Two others, not large enough to be included in that list, are of interest for their effects. That of March 16, 1906 was accompanied by visible faulting along an east-west zone in west central Formosa (Omori, 1907b). That of April 20, 1935, was accompanied by block faulting in the northwest part of the island; it is the subject of two special publications. One, completely in the Japanese language, was published at Taihoku in 1937; the other contains a few abstracts and tables in English, and was published in 1936 as supplementary volume No. 3 of the Bulletin of the Earthquake Research Institute (Tokyo). In these two cases shallow focus is consequently thoroughly established, which is important in a region where intermediate shocks are known to occur. Formosa occupies a sharp bend in the seismic belt, presumably associated with an intersection of the east-west structures, just alluded to, and the more conspicuous structures longitudinal to the island.

Useful historical data are available for Formosa only in comparatively recent years. In the Philippines, on the other hand, records for more than three centuries are available (Masó, 1927a; 1927b); the region is very active; the seismicity being comparable with that of Formosa and most parts of Japan. Recent earthquakes and instrumental epicenters have been discussed in a series of papers by Repetti (1931a; 1931b; 1931c; 1932; 1935; 1940).

The active belt plainly continues along the west coast of Luzon, where the intermediate shocks in general occur farther from the Pacific than the shallow ones, with the result that their epicenters fall off shore in the China Sea, while the shallow shocks are close to the coast.

PHILIPPINES AND MOLUCCAS

The distribution of seismic activity, some of which is very intense, has an important bearing on the complicated structural problems of the large

area discussed in this section. This is roughly triangular, with the Philippines at the northern apex and the base extending from Borneo over Celebes to the Moluccas. Figure 9 is complete for intermediate and deep shocks; for shallow shocks supplementary data were given in Table 12.

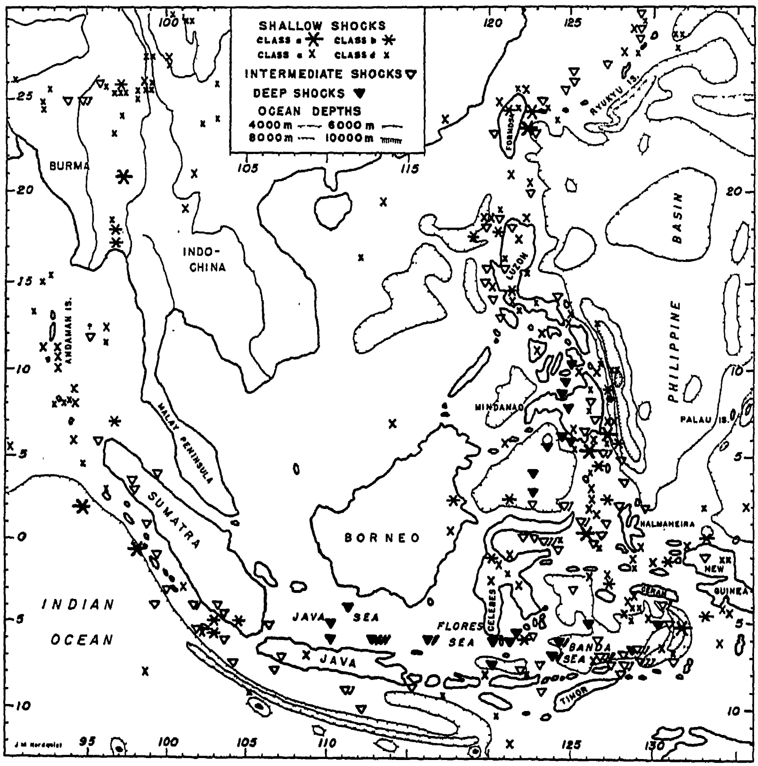

FIGURE 9.—*Map of epicenters, Formosa, Philippines, and East Indies*

For studying the high activity of the Philippines a large body of data assembled at Manila is available. (*See* papers by Repetti and Masó referred to above.) Macroseismic observations are regularly collected, and three secondary stations are maintained which supplement the seismograms of the chief station at Manila. Because of the different state of culture, and the smaller number of active stations, data for the Philippines are less complete than for Japan; but they compare well with those for most other regions of equal seismicity.

The active belt descending from Formosa along the west coast of Luzon turns sharply to the east and follows the eastern margin of the Philippine group to the Moluccas. However, west central Luzon appears to be a

region of intersection of two seismically active structural belts, not unlike the region of intersection in Formosa.

Shallow and intermediate shocks continue down the west coast to Mindoro; but there is no evidence for seismicity in the structural belt which

TABLE 12.—*Additional earthquake epicenters in the Philippines and the East Indies*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1925, April 22	23:10:42	½ S.	129 E.	C	c
1927, June 11	02:32:09	1½ S.	130 E.	B	c
1924, Feb. 13	22:50:13	2½ S.	122 E.	B	c
1924, July 29	05:18:45	2½ S.	120 E.	B	c
1925, Dec. 29	16:04:11	1½ S.	120½ E.	B	c
1936, July 6	18:21:01	½ S.	126½ E.	B	d
1938, May 19	17:08:21	1 S.	120 E.	B	b
1924, April 13	13:48:00	½ N.	117½ E.	A	c
1913, March 14	08:45:00	4½ N.	126½ E.	B	b
1930, July 21	14:06:02	7 N.	114 E.	B	c
1919, April 27	00:22:05	11 N.	123 E.	C	c
1937, Aug. 20	11:59:16	14½ N.	121½ E.	A	b
1936, Oct. 19	12:04:17	2 S.	127 E.	B	c
1938, June 9	19:15:08	3 S.	127 E.	A	b
1935, Dec. 29	23:37:20	3½ S.	128½ E.	B	c
1936, Nov. 30	23:45:48	2 S.	126 E.	B	c
1935, March 16	07:50:12	4 S.	129 E.	B	d
1938, Aug. 30	17:08:42	4 S.	128½ E.	B	d
1930, Nov. 9	19:08:38	½ S.	132 E.	A	c
1934, July 19	01:27:35	½ S.	133 E.	B	b
1936, Feb. 15	12:46:57	4½ S.	133 E.	B	b
1937, Nov. 5	09:28:30	4 S.	134 E.	C	c
1926, Dec. 14	17:10:32	12 S.	121 E.	C	c
1923, April 19	03:09:08	2½ N.	117½ E.	B	b

here branches off to the southwest, passing through Palawan to Borneo. Borneo itself is part of an old stable land mass, discussed in a later section.

The principal active belt in the eastern Philippines is associated, directly or secondarily, with a great fracture system referred to by Willis (1937; 1940) following Becker, as the Philippine Fault. Repetti (1935) calls it the Master Fault, and draws it northwest across central Luzon, thus emphasizing the structural intersection in the west. This line includes the earthquake of August 20, 1937 (Table 12), which caused damage at Manila and was destructive farther east. In its southern course, passing Mindanao, this seismic belt has all the characteristics associated with the most active regions on the boundary of the Pacific. To the east is

the deepest oceanic trough known, the Mindanao Trench (Philippine Deep), associated with large negative gravity anomalies (Meinesz, *et al.*, 1934); the shallow shocks occur principally on the marginal shelf between this deep and the islands west of it. The seismicity increases southward, reaching a high maximum off southern Mindanao, where two great shocks (1918, 1924) are taken from Table 5. Farther west is the great fracture system, near which there is active and recently extinct volcanism, and a few shocks at intermediate depth are known. Still more to the west is a north-south line of shocks at depths from 300 to 610 km.

Despite the conspicuous and characteristic development here of all the characteristics of Pacific marginal structure the Philippine Basin is continental and not Pacific in character, although it may include isolated small regions of Pacific type. Except for the higher seismicity this is similar to the conditions on the South American coast. Many of the same characters are developed along the Sunda arc, discussed in the following section, where the area external to the arc is certainly not Pacific.

An epicenter at 11° N. 123° E. (Table 12) represents an active area in the central Philippines. There are historical accounts of violent earthquakes here, on the island of Panay, particularly in 1621 and 1787.

The shock in the Sulu Islands, at 6° N. 121° E. (Sept. 15, 1932) was felt strongly on Jolo, and was perceptible on Mindanao. Other shocks are known here.

South of Mindanao the complexities increase, and any interpretation of the epicenters is necessarily influenced by the supposed structural trend lines, particularly as shown by the forms of island arcs and submarine troughs, and by the recent data on gravity anomalies (Meinesz, 1933; 1940). Shocks are frequent, and often large; but the structures are so closely involved that an error of 1 degree will often greatly affect the structural interpretation of an epicenter. Such errors, and even larger ones, are probable in most cases. There is only one station local to the most important area, at Amboina (south of Ceram); the station at Butuan on Mindanao is not sensitive enough to be of much help, and the next nearest stations are Manila, Palau (Caroline Islands), Batavia (Java), and Brisbane (Queensland). Few such areas exist where the establishment of a network of local stations might reasonably be expected to yield much information of a sort which would bear on structural and dynamical problems the world over. Reports of shocks felt here are difficult to use, on account of the relatively small land area and the frequent deep-focus earthquakes.

The earthquake of March 14, 1913 (Table 12) was violent in the Sangi Islands and on Mindanao, with a very wide area of perceptibility. The calculated magnitude was not quite large enough for inclusion in Table 5.

The belt of shallow shocks can be traced from Mindanao past the Sangi Islands to a point off the northeastern promontory of Celebes. Note

the great shock of May 14, 1932 (Table 5). The belt of negative gravity anomalies runs southward to the east of these epicenters, accompanied by an oceanic trough less well marked than the great deeps to the north of it, and then swings southwestward toward Celebes.

The occasional large shocks on all sides of Celebes are difficult to assign to definite seismic belts. That of December 14, 1932, mapped at 2.4° N. 121° E., is large and accurately located. Just south of Celebes is the large shallow shock of March 3, 1927 (Table 4). With these should probably be included such historical shocks as that of 1820, destructive at Makassar and followed by a tsunami. (*See*, Sieberg, 1932a, p. 843). The deep shocks in the same area will be discussed with the Sunda arc.

A belt of intermediate shocks follows the northern peninsula of Celebes and extends eastward to Halmaheira, following a well-known volcanic line which cuts across the structures associated with shallow earthquakes; from Halmaheira this belt turns north toward the Philippines, here running on the east side of the belt of shallow shocks. Near the parallel of 2° N. north of Celebes are three shocks at depths of not quite 300 km. Still farther north are two shocks at depths of 600 and 670 km., these may be associated with the north-south belt of deep shocks in the Philippines.

The current suggestion is that the structural belt followed by shallow earthquakes swings east from central Celebes, and runs round the Banda Sea to connect with the Sunda arc. This is very speculative; certainly the epicenters, as mapped, would leave plenty of room for connections of different character.

SUNDA ARC

The seismic area of the Netherlands East Indies is bounded on the south by epicenters in the structural belt which runs from Ceram round the Banda Sea, thence west by way of the Lesser Sunda Islands and the coasts of Java and Sumatra to the Nicobar and Andaman Islands.

Shocks are more frequent about the Banda Sea than Figure 9 suggests. Locations are not easy here, even when the depth of focus is well determined. Uncertainty as to the focal depth is common, and seriously affects the accuracy of the resulting epicenters. One great shallow shock is well located (Feb. 1, 1938; Table 5). This and other shallow shocks are near the Weber Deep. The belt of negative gravity anomalies follows the same course round the inside of the structural arc. Shocks at intermediate depth are here most frequent on the south side of the Banda Sea, where they seem to align with the east-west trend of the main Sunda arc. The deep shocks mapped in the Banda Sea east of 125° originated at depths from 370 km. to 500 km.

The seismicity of the Sunda islands from the Banda Sea to central Java is only lightly indicated on Figure 9. Most of the shocks are either shallow

or in the upper part of the intermediate range—which, it is generally not possible to decide. Historical data indicate moderate activity here, including the subsidiary arc which extends on the south side through Sumba and Timor.

TABLE 13.—*Additional earthquake epicenters near the Andaman Islands*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1930, July 17	14:34:44	8 N.	94 E.	B	d
1925, June 28	13:41:45	11 N.	93 E.	B	c
1925, May 13	23:54:34	11 N.	92 E.	B	c
1929, Aug. 1	05:01:48	10 N.	93 E.	B	c
1922, Oct. 17	06:37:59	12½ N.	96 E.	B	c
1928, May 19	03:28:42	13½ N.	91½ E.	B	c
1927, July 29	00:03:11	15 N.	87 E.	B	c
1926, May 29	22:37:32	15 N.	92 E.	B	d
1935, Nov. 25	10:03:02	6 N.	94 E.	B	c
1936, April 19	09:04:00	10½ N.	93 E.	B	c
1937, Nov. 30	00:40:27	5½ N.	90 E.	B	c
1939, July 18	11:24:09	8 N.	93 E.	B	d

Through the Flores Sea and Java Sea, north of the islands, passes a belt of shocks at depths ranging from 600 to more than 700 km. (Fig. 9; Berlage, 1940). This belt includes the deepest known earthquakes; of these, that of June 29, 1934 near 7° S. 124° E. (No. 109) is notable as a very great shock. Earthquakes at other depths occur associated with the belt, which presumably includes the shocks at depths from 370 to 500 km. in the Banda Sea. The shock south of Celebes at 7½° S. 120° E. (No. 105, Oct. 17, 1933) apparently is only 420 km. deep. The large normal shock just south of Celebes can hardly have any significant connection with these deep earthquakes.

Increase in activity is notable off western Java, extending along the coast of Sumatra, where two great shocks are indicated on the map, and others are known from historical data. Because of the proximity of the principal station at Batavia, epicenters here are more accurate than in many other parts of the East Indies, and many authors have endeavored to determine the relation between the earthquakes and the submarine troughs, minor island chains, and gravity anomalies off these coasts. (*See* Meinesz, *et al.* 1934). Before the establishment of the stations it was commonly supposed that the strong shocks of Sumatra and Java originated on those islands; but it then became evident that the epicenters of most of the larger shallow shocks are offshore, and that the better located of these are close to the chain of minor islands referred to, which is in the line of

the belt of large negative gravity anomalies. However, shocks at depths of 70 to 100 km. are also frequent, and their epicenters are closer to the coast, or even inland. At 4° N. 99° E., on the northeast coast of Sumatra, is a shock with depth of 200 km. (No. 102, July 4, 1936).

The Sunda arc extends into the Nicobar and Andaman Islands; but the seismicity is distinctly lower here than off Sumatra, so that a search has been made for additional shocks (Table 13; *see also* the great shock of June 26, 1941, 11:52, probably near 11° N., 93° E.). The line of epicenters follows the islands, but those near 15° N. are rather farther west than might be expected, and further continuation of the line is doubtful. On the other hand, a line of shallow shocks, some of them large, extends just east of the meridian of 96°, from a point north of Sumatra, across the shallow sea and far into Burma.

THE TRANS-ASIATIC ZONE

GENERAL STATEMENT

The earthquakes of continental Asia present the only important exception to the rule that the principal seismicity of the globe is aligned along comparatively narrow belts. In eastern Asia is an area thousands of miles wide, with shocks of moderate to large magnitude along so many structures within it that on the scale of the world map they appear to be scattered at random.

This first impression is much modified on inspection of Figure 10. The structural lines shown are taken from Born (1933), Willis (1939), Arni (1939), Clapp (1940), Mushketov, (1936a; 1936b), and Wilser (1928). Additional epicenters are from Table 14, and a few from Table 15. The distribution of seismicity is by no means random, but is closely related to the major structures. There is greater activity, in number and in magnitude of shocks, than in other similarly complex continental areas.

The wide eastern area is roughly triangular, narrowing westward as the structures converge toward the Pamir plateau. From the Hindu Kush westward the zone spreads again through Baluchistan and Iran, then contracts and enters Europe through Asia Minor.

The zone as a whole is characterized by the only great shallow shocks, and the only shocks at intermediate depth, outside the Pacific belt. No shocks deeper than 300 km. have been found here.

The rather well-defined southern limit of the zone is the southern front of the Asiatic belt of Alpide structures; the shocks near this front will be discussed first.

THE ALPIDE BELT

The frontal structures of the Alpide belt in southern Asia are a series of mountain arcs, convex to the south (except the Burma arc, which is convex to the west). In spite of certain evident differences, these arcs are usually

TABLE 14.—*Additional earthquake epicenters in Asia and the eastern Mediterranean*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1925, Dec. 22	05:05:30	21 N.	101½ E.	B	c
1929, March 22	03:03:54	24 N.	103 E.	C	d
1927, March 14	17:37:39	26 N.	103 E.	B	d
1926, Aug. 11	05:47:35	29½ N.	101½ E.	C	d
1927, July 2	20:38:46	29½ N.	101 E.	C	d
1930, Aug. 24	10:51:16	30 N.	100 E.	C	d
1930, April 28	12:59:27	32 N.	100 E.	C	d
1928, July 19	20:13:50	31½ N.	102½ E.	B	c
1918, Feb. 13	06:07:13	24 N.	117 E.	B	c
1927, June 2	16:37:34	23½ N.	81 E.	B	c
1930, Sept. 22	14:19:11	25 N.	94 E.	A	c
1930, Sept. 29	13:29:00	22 N.	68½ E.	B	d
1926, May 19	21:13:55	26½ N.	59 E.	B	d
1929, Oct. 29	05:53:39	27½ N.	54½ E.	A	d
1930, May 11	22:35:46	27½ N.	55 E.	A	c
1930, April 15	09:56:27	29 N.	54 E.	B	d
1927, July 7	20:06:24	27 N.	62 E.	B	c
1927, May 9	10:31:47	27½ N.	56 E.	B	c
1928, Oct. 15	14:19:41	28½ N.	67½ E.	A	c
1930, Sept. 2	18:58:48	30 N.	51½ E.	B	c
1923, Sept. 22	20:47:38	29 N.	56½ E.	B	c
1924, Aug. 13	23:57:50	29½ N.	90 E.	B	c
1929, March 25	03:47:04	29 N.	94½ E.	A	d
1928, Sept. 1	06:09:00	29 N.	68½ E.	B	c
1927, July 11	13:04:07	32 N.	35½ E.	A	c
1927, July 22	03:55:10	34½ N.	53½ E.	B	c
1929, July 15	07:44:14	32 N	49½ E.	A	c
1930, May 9	07:07:22	34½ N.	32 E.	A	c
1928, June 24	04:34:34	36 N.	71 E.	B	c
1926, March 22	16:24:10	36 N.	70 E.	B	d
1928, Nov. 14	04:33:05	35 N.	73 E.	B	d
1926, Aug. 6	22:45:54	35½ N.	78½ E.	B	c
1926, June 4	06:50:58	35 N.	89½ E.	B	c
1921, April 20	16:04:20	34 N.	33 E.	C	d
1924, Feb. 18	17:03:56	34½ N.	34 E.	B	d
1930, Sept. 1	17:43:13	35½ N.	81 E.	A	c
1926, March 18	14:06:09	35 N.	29½ E.	B	c
1920, Oct. 12	06:54:48	36 N.	81 E.	B	c
1928, March 7	22:43:24	37½ N.	102 E.	B	c
1925, Feb. 7	12:14:58	37 N.	19 E.	B	d
1929, Aug. 4	09:03:53	36 N.	31 E.	B	d
1928, Aug. 23	06:15:55	36½ N.	36 E.	B	d
1928, Feb. 25	17:23:58	37½ N.	67 E.	B	d
1924, Sept. 10	11:59:30	37 N.	32 E.	B	d
1924, July 3	04:40:06	36 N.	84 E.	B	b
1925, Aug. 7	06:46:37	38 N.	30½ E.	B	c
1930, Sept. 11	12:36:44	37 N.	31 E.	A	c

TABLE 14.—*Concluded.*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1927, March 15	21:48:35	38½ N.	97½ E.	B	c
1925, Dec. 7	08:34:30	37 N.	76½ E.	B	d
1930, July 13	19:27:17	38 N.	98½ E.	A	c
1928, March 31	00:29:47	38 N.	27 E.	A	c
1924, Sept. 16	02:36:00	39 N.	70½ E.	B	c
1929, May 18	06:37:51	40 N.	38 E.	A	c
1927, April 30	13:56:47	38½ N.	78 E.	C	d
1928, Nov. 6	13:42:35	40 N.	53½ E.	B	d
1923, April 29	09:34:35	40 N.	37 E.	C	c
1924, Sept. 13	14:34:05	40 N.	42 E.	B	c
1923, Dec. 28	22:24:52	39½ N.	68 E.	B	c
1924, July 6	18:31:49	40½ N.	73½ E.	B	c
1929, June 13	22:15:51	43 N.	66 E.	C	d
1930, June 17	20:07:22	43½ N.	102½ E.	C	d
1929, Sept. 4	22:24:57	43 N.	67 E.	B	d
1927, Sept. 23	13:54:20	42½ N.	84 E.	B	c
1924, July 12	15:12:34	40½ N.	73½ E.	B	c
1929, Feb. 10	17:20:16	44 N.	44 E.	B	d
1929, June 3	20:29:47	43 N.	67 E.	A	c
1927, June 26	11:20:48	44½ N.	34½ E.	A	c
1923, Sept. 14	12:57:31	48 N.	96 E.	B	c
1928, Nov. 23	04:23:30	47½ N.	30 E.	B	d
1922, Aug. 25	19:29:40	50 N.	91 E.	B	c
1937, July 31	20:38:44	34½ N.	115 E.	A	c
1937, Aug. 1	10:41:00	35 N.	116 E.	A	c
1934, June 13	22:10:20	20 N.	62½ E.	B	b
1934, June 23	05:19:53	33 N.	92½ E.	A	c
1934, Aug. 7	11:49:58	43 N.	87½ E.	B	d
1934, Dec. 15	01:57:37	31½ N.	39½ E.	A	b
1935, Jan. 3	01:50:26	30½ N.	88 E.	B	c
1935, Jan. 4	14:41:25	40½ N.	27½ E.	A	c
1935, March 5	22:15:57	30 N.	80 E.	B	d
1935, April 11	23:14:40	35 N.	52 E.	B	c
1935, May 13	19:53:38	20 N.	101 E.	B	c
1935, July 5	17:53:01	38 N.	67½ E.	A	c
1935, Nov. 1	16:22:01	20½ N.	103½ E.	B	c
1936, May 27	06:19:19	28½ N.	83½ E.	A	c
1937, Jan. 2	14:04:02	35 N.	25 E.	B	d
1936, June 14	17:01:30	37 N.	35½ E.	A	d
1936, June 30	19:26:06	33 N.	60 E.	C	d
1936, Sept. 21	11:41:33	41 N.	33 E.	A	d
1937, Dec. 25	09:55:55	57 N.	110 E.	B	c
1938, Feb. 14	02:54:16	40½ N.	53½ E.	A	c
1938, March 14	00:48:33	21½ N.	75½ E.	A	d
1938, Oct. 19	04:13:26	49 N.	90 E.	B	d
1939, Jan. 22	04:41:08	56 N.	130 E.	B	d
1939, May 26	09:40:35	53 N.	109 E.	B	d

regarded as analogous to the marginal structures of the Pacific region, such as those of the Japanese islands and the Sunda arc. The analogy refers both to the structural forms, and to the geologic age of the component rocks. The alluviated depression of the Ganges, fronting the Himalayan arc, is often considered as a foredeep of the Pacific type, and the peculiarities of gravity in that region are compared with the gravity anomalies over the Pacific troughs. The seismicity also shows some similarity, as strong shallow earthquakes occur on the outside of the mountain arcs, between them and the presumed foredeeps, and intermediate shocks occur toward the interior of the arcs. However, the shallow activity is in general not concentrated on the front of the arcs, as in most of the Pacific area, but is supplemented by shocks in structures extending over a wide zone back of the margin. Furthermore, the crustal blocks against which these mountain arcs front are not part of the Pacific structure, but are old stable continental shields. The three eastern arcs are grouped about the old land of peninsular India, and those to the west are similarly related to the stable masses of Arabia and Africa.

For shallow shocks, the general activity is moderate, with occasional earthquakes of great magnitude. The seismicity is more nearly comparable with that of California or New Zealand than with that of Mexico or of Japan. Shallow shocks are in a large majority. Intermediate shocks are usually well defined; occasionally there is doubt as to focal depth slightly greater than for ordinary shallow shocks, but this is not so common as in the Pacific belt. In India, two great shocks are known (1819, 1897) in which the surface was broken by faulting.

Intermediate shocks have been identified in five areas surrounding the stable mass of India, and at four localities in Asia Minor and Europe. The most remarkable are those of the Hindu Kush. At least 40 shocks are known to have occurred at depths near 230 km. under a small area at about 36½° N. 70½° E. (indicated by the large triangle in Fig. 10), at dates from 1907 to 1940. Those of 1907, 1909, 1921, 1933, 1937, and 1939 were certainly large earthquakes, and several of them were destructive. This is very different from the behavior of intermediate shocks in the Pacific belt, where successive earthquakes usually occur at different points of an active line. The same behavior is, of course, characteristic of shallow shocks. In the Hindu Kush there are a few shocks at shallower depth; their epicenters usually also differ slightly from that of the principal group. Similar repetitions occur from the intermediate focus in Rumania.

The intermediate shocks of the Burma arc are distributed in a way more like that described for the Pacific belt. Those near 25° N., all near 130 km. in depth, show a definite range along the arc; and to the north of them is the shock of May 10, 1926 (No. S 32), which may have any depth down to 100 km. The Burma arc presents other anomalies. It is convex west-

ward, and connects at a sharp angle with the Himalayan arc. This angle is obviously a region of great crustal disturbance, which is expressed by high regional seismicity, comparable with that near the Pamir Plateau, round the analogous angle at the other end of the Himalayan arc.

Except for intermediate shocks, the Burma mountain arc appears to be almost completely nonseismic. Shallow shocks ascribed to it are shown, on revision of the instrumental data, to have originated on the north-south line east of the arc. This line, which follows some evident structures, passes southward through Pegu, and apparently extends nearly to Sumatra. In this, seismological evidence fails to support the common practice of running the Burma arc into the active arc of the Andaman Islands, thereby connecting the Asiatic structures and seismic belts with those of the East Indies. Notwithstanding, the Sunda arc may be an eastern member of the Alpide series.

The south front of the Himalayan arc has been the origin of many great shocks. That of 1897 originated near Shillong (Assam) in the outlying hills south of the Himalaya; and the large earthquakes of 1905 and 1934 (Table 5) had similarly placed epicenters farther west. The epicenter of the great shock of 1819, in the Runn of Cutch at about 24° N. 69° E., occupies an anomalous position. The association of the mountain arc on the coast of Oman with the arcs of the Alpide belt is an unsettled question; a shock of 1884 was destructive at and near Muskat (Sieberg, 1932a, p. 795).

The most westerly of the southern structural arcs of the Alpide belt extends from northern Syria through the Mediterranean south of Cyprus and Crete. The instrumentally determined epicenters mark this out very plainly as the southern limit of the active area. This arc is identical with the southern boundary of the region Neo-Europa as indicated on the well-known map by Stille (1924).

EASTERN AND CENTRAL ASIA

The eastern coast of continental Asia, from China to Manchuria, is fairly quiet, with an occasional large shock. There is a definite gap between the high activity of the Japanese and Philippine areas and the continental seismicity.

Strong shocks are often destructive in the western Chinese provinces of Szechuan and Yünnan. (*See also* Heim, 1934.) In the mountain ranges of Tibet are several epicenters. The Kuen Lun shock of 1937 (Table 5) was a great earthquake. In view of the fragmentary nature of the macroseismic information which reaches us from this remote region, it is fortunate that the instrumentally located epicenters are satisfactory. The single epicenter in the Altyn Tagh represents a well-observed shock on September 25, 1933.

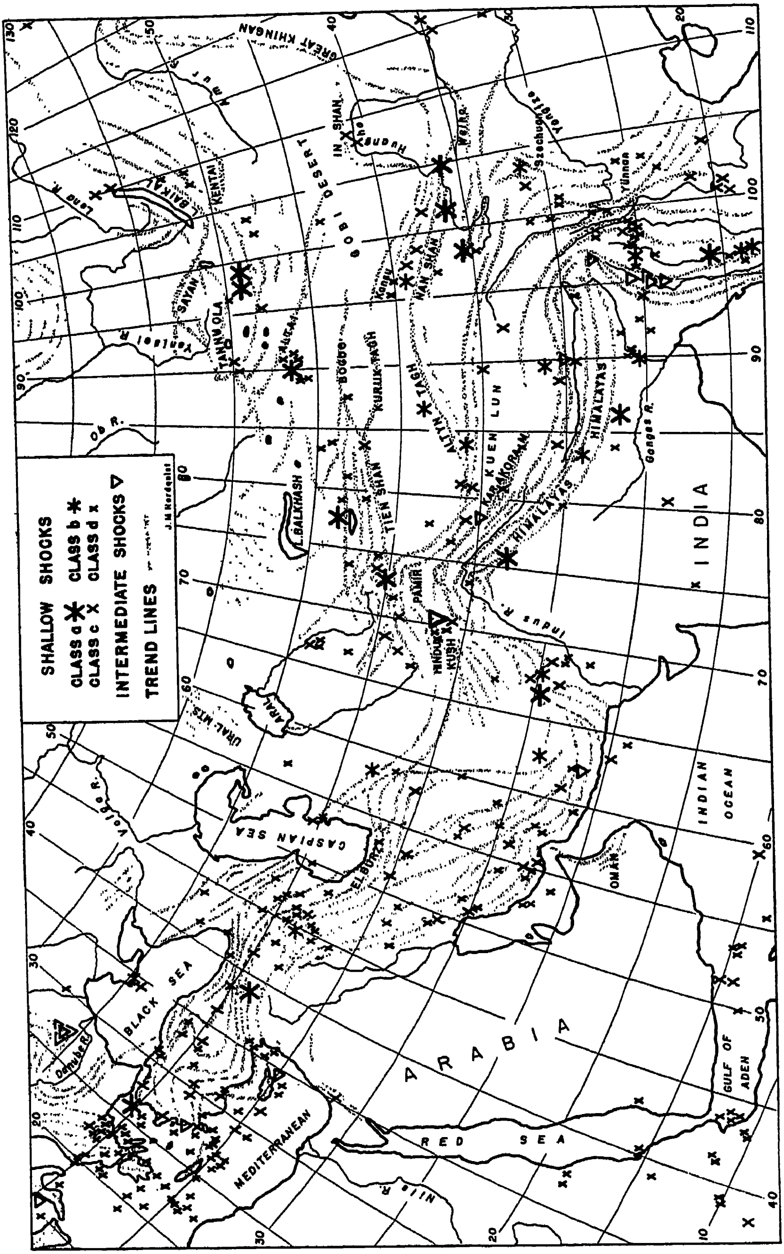

FIGURE 10.—*Map of epicenters and structural trend lines for continental Asia*

In the Nan Shan and eastward shocks are frequent, and many other epicenters could have been added. The adjacent province of Kansu with two great shocks in Table 5 (1920, 1927) is one of the most frequently shaken parts of China. The history of destructive shocks allows us to extend the seismic belt eastward, at least far enough to include the valley of the Weiho, which enters the Huangho from the west near 34° N. 110° E. This has long been one of the most thickly settled areas in the world, so that merely destructive shocks with considerable loss of life might not prove high local seismicity. However, the reported effects are extreme; the earthquake of 1556 in this region is said to have taken 830,000 lives. If the earthquake history can be trusted, it suggests a deflection to the north rather than an eastward continuation of the active line. However, strong shocks have occurred more nearly to the east; the two large shocks of July 31 and August 1, 1937 were well recorded and are mapped near 35° N. 115° E. A little farther east, destructive shocks have occurred in Shantung (January 8, 1910).

North and west of this line is the stable area of the Gobi Desert, and beyond is the broad and not very sharply defined belt of activity bounding the Asiatic seismic zone on this side. The boundary belt extends across most of Asia, following the southern half of the belt of great depressions marked by Lake Baikal, Lake Balkash, the Aral and Caspian seas, and the Black Sea. The great stable area of northern Asia lies on the other side of it. There is not a very wide gap between the most northeasterly shocks of this group and those of the Arctic belt near the mouth of the Lena. If this gap were closed, there would exist a seismic belt completely surrounding the Eurasian mass by way of the Arctic, the North Atlantic, the Azores, the Mediterranean, the Black Sea and central Asia. The Asiatic boundary belt resembles the Arctic and Atlantic belts in the absence of deep shocks, but differs in greater seismicity, and in the greater magnitude of its largest shocks. Table 5 includes five great shocks with epicenters ranging from the Pamir Plateau toward Lake Baikal. The alignment of activity is not along the strike of the more evident surface structures of the region (Fig. 10) which are mostly Palaeozoic or older. Instead, the active belt follows the region of highlands between the great depressions and the Gobi Desert.

The structures associated with the Caucasus and the Crimean mountains are also active. (*See* Mushketov, 1936a). Between the Aral Sea and the Caspian, at 42.9° N. 56.5° E., the single well-located shock of July 14, 1933 shows that the boundary of the active zone must be drawn well toward the north, in line with the active east-west structures north and northwest of the Tien Shan.

MEDITERRANEAN EUROPE

Figure 2 shows that, if the shocks of a few decades were used solely, western Europe would hardly be included among the seismic regions of the

world. The major active zone extending across Asia has a well-defined terminal section, which includes Asia Minor, the Aegean, and the southern Balkan peninsula, and is bounded on the south by the arc passing Cyprus and Crete. West of this the seismicity is comparatively minor. Unless the investigator cares to risk errors in interpretation by using data for small shocks, he must consider the activity over a long period.

In Europe, historical data confirm the impression gained from study of shocks of a limited period. The southeastern area is the only part comparable in seismicity with the chief active belts of the globe. Most of the remaining strong shocks have occurred in Italy and Sicily, and round the southwestern shores of the Mediterranean.

In contrast with the importance of the Alpide seismicity in Asia, the Alpine system itself is only mildly seismic. The Alps are subject to frequent small shocks, but no more so than many other mountain systems of the world, outside the major seismic zones and belts. The shocks of the southern Alps belong with the moderately seismic region of Italy. In the north, the large shock destructive at Basel in 1356 is an isolated instance, comparable with others which will be noted in discussing the more stable areas of the world.

The Carpathian system is less active than the Alps, except for the remarkable group of Rumanian shocks. Several of these including the destructive shock of November 1940 will be found in our lists of intermediate shocks, with depths near 150 km. and epicenters near 46° N. 26½° E., at the sharp bend in the Carpathian ranges north of Bucharest. In situation, and in repetition from one focus, these shocks resemble the Hindu Kush group. The historical record includes other shocks (1790, 1829, among others) probably from the same focus, reported destructive at Bucharest and perceptible at surprisingly great distances.

Great shocks at intermediate depth occur in the Aegean and the eastern Mediterranean. One of these (No. 252; 1926, June 26; Fig. 10) was destructive at many widely separated points, with an enormous area of perceptibility. This is the most recent shock of a group first noticed by Schmidt (1881), who concluded that these shocks must have a focal depth greater than those of ordinary earthquakes, and associated their occurrence in this region with the volcanic activity represented by Santorin. Sieberg, who personally investigated the 1926 shock, has published a special study of the group (Sieberg, 1932 b), which he terms *Levantinische Riesenbeben*. Some of these earthquakes, particularly that of 1870 which was violent in Lower Egypt, seem to have originated farther south. Shock 251m, on January 20, 1941, at a depth of about 100 km., was destructive on Cyprus.

Oldham (1923) drew attention to the shock of August 7, 1895 in northern

Italy, for which the macroseismic observations indicate a depth of the order of 100 km. The shock of April 13, 1938 (No. 253m) originated north of the Lipari Islands at a depth of 270 km., which makes it the deepest known earthquake outside of the circum-Pacific belt.

Apart from these, earthquakes in the European area are all taken to be

TABLE 15.—*Additional earthquake epicenters in North Africa*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1930, Aug. 9	18:09:26	34 N.	5 W.	C	d
1926, Oct. 11	06:38:52	36 N.	3 W.	B	d
1927, Sept. 8	08:52:50	36 N.	3½ W.	B	d
1923, July 9	15:31:16	35½ N.	4 W.	C	d
1928, Aug. 24	09:44:15	36 N.	0	B	d
1924, March 16	10:17:25	35 N.	6 E.	B	d
1920, Feb. 25	17:56:23	35 N.	9½ E.	C	d
1924, Nov. 5	18:54:25	36 N.	4 E.	B	d
1929, Dec. 13	04:45:27	36 N.	14 E.	B	d
1935, April 19	15:23:26	32 N.	15 E.	A	b
1936, June 13	00:32:42	33 N.	22½ E.	B	d

shallow, although the depth of focus varies somewhat, being presumably deeper under the Alps and immediately north of them than elsewhere.

Historical records amply justify drawing an active line along the Apennines, though most of these shocks, in spite of their locally disastrous effects in towns where weak construction is prevalent, were not of large magnitude. As the line enters Calabria and turns into Sicily, stronger shocks, such as those of 1783, are encountered. Here the seismic line again parallels the southern boundary of Stille's *Neo-Europa*. It extends westward along the African coast, where the recent activity has been high enough so that additional epicenters could be taken from the International Summary and more recent bulletins (Table 15; Fig. 12). Notable activity occurs eastward along the coasts of Tunis and Libya. The shock on April 19, 1935, at 32° N. 15° E., was the largest in the western Mediterranean in recent years.

All this activity is close to the coasts, no epicenters being found in the western Mediterranean basin. The north coast is also active, particularly in southern Spain, though less so than the south coast. The seismic belt of the central Atlantic has a branch running eastward through the Azores, which links up naturally with the Mediterranean activity. This partly hypothetical seismic line should presumably include the great Lisbon earthquake of 1755.

OTHER SEISMIC BELTS

GENERAL CONSIDERATIONS

Much of the seismicity remaining to be discussed is concentrated along two narrow belts, which are chiefly oceanic. The better known of these passes centrally through the Atlantic Ocean, along the Mid-Atlantic Ridge. It extends into the Arctic, and across the polar area to the north coast of Siberia. The other similar belt passes from Arabia southward through the western Indian Ocean into the Antarctic. For convenience, the seismicity of the East African rift zones is also discussed here.

No great shocks are known to have occurred in these belts, and large shocks are rare. Most of the shocks used in this study are given in supplementary tables for the four groups; they result from careful search for epicenters in these regions. All shocks in the International Summary from 1920 on have been examined, and the more important recent shocks have been added. Nearly every available instance has been revised and placed on the maps, except in very active areas such as the Azores and the equatorial Atlantic, where no further duplication of epicenters was necessary. Only hopelessly small and poorly recorded shocks have been rejected. In this work, all areas have been canvassed with equal care, with a view to discovering branches of the main belts or isolated epicenters, some of which are mapped. No doubt remains as to the objective reality of these narrow active belts.

None of these shocks give indication of any unusual focal depth. This is all the more important because the active belts pass through well-known regions of volcanic activity, so that a series of exceptions is provided to the close association of intermediate shocks with lines of active or recently extinct volcanoes, which is a notable feature of the circum-Pacific belt, though less evident in Europe and Asia.

Instrumental data were applied to the investigation of the seismicity of these regions by Tams (1922; 1927a; 1927b; 1928; 1931). For the discussion of bottom contours of the Atlantic and Indian Oceans *see* Littlehales (1932), Wüst (1934; 1939a; 1939c) and Vaughan, *et al.* (1940).

ARCTIC BELT

The seismicity in the Arctic region north of Europe was first studied by Tams (1922), who recognized this activity as a northward extension of the Atlantic belt into the polar region. He also published a separate discussion (Tams, 1927b) of earthquakes in the region of the Nordenskjöld Sea (near the mouth of the Lena) but refrained from suggesting a direct connection between these and the other Arctic shocks. Such a connection seems first to have been emphasized by Rajko and Linden (1935) and by Mushketov (1935). Their map shows epicenters in the Arctic which clearly fall along a continuous belt. This map has been reproduced by Heck (1938a).

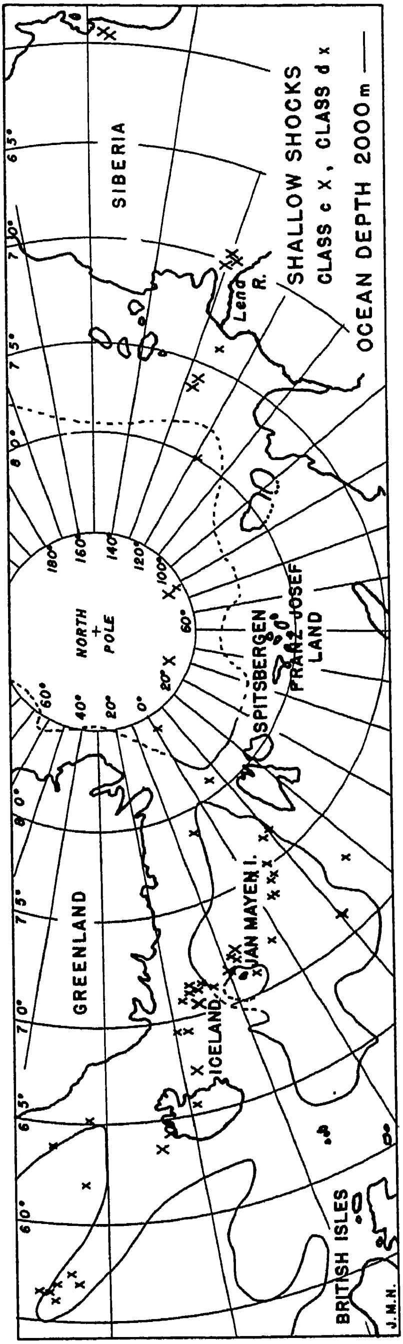

FIGURE 11.—*Map of epicenters, north polar region*

Figure 11 and Table 16 show fewer epicenters. The Russian workers and Heck have accepted a number of epicenters from the International Summary which appear insufficiently established. On the other hand,

TABLE 16.—*Additional earthquake epicenters in the Arctic*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1921, Aug. 23	20:17:28	67 N.	18 W.	B	c
1925, Nov. 28	08:14:53	69 N.	18 W.	C	d
1929, June 27	22:39:07	71 N.	6 W.	A	d
1923, Oct. 10	07:11:18	72 N.	10 W.	A	c
1924, Oct. 10	09:21:17	71 N.	16 W.	C	d
1927, July 16	02:16:03	71 N.	17 W.	C	d
1922, April 8	20:42:21	72 N.	8½ W.	B	c
1929, Aug. 6	01:30:13	72 N.	8 W.	B	d
1927, Oct. 30	03:09:04	71½ N.	14 W.	B	d
1930, Oct. 11	03:06:22	71 N.	13 W.	A	d
1930, March 15	09:13:30	78½ N.	4 E.	C	d
1926, Aug. 6	05:23:58	86 N.	85 E.	B	c
1927, Jan. 7	10:43:22	80 N.	117 E.	C	d
1929, Aug. 16	23:29:02	80½ N.	5 E.	C	d
1927, Sept. 6	07:16:09	77 N.	10 E.	B	d
1923, May 30	08:30:46	77 N.	127 E.	B	c
1923, May 30	17:56:42	77 N.	127 E.	C	c
1926, Dec. 25	05:13:20	75 N.	5 E.	C	d
1927, Aug. 7	23:57:05	74 N.	4 E.	B	d
1927, Aug. 8	00:25:28	75 N.	2 E.	B	d
1926, April 9	10:04:50	74 N.	125 E.	C	d
1924, March 12	13:52:48	73 N.	2½ E.	B	d
1924, July 19	02:50:09	73½ N.	4 E.	C	d
1924, July 25	19:36:22	72½ N.	16 E.	C	d
1929, June 10	23:03:14	71 N.	10 E.	A	c
1927, Nov. 14	04:56:29	70 N.	128 E.	A	c
1927, Nov. 15	21:48:46	70½ N.	128 E.	A	c
1928, Feb. 3	13:47:35	70½ N.	128 E.	A	c
1935, Sept. 30	19:00:42	84 N.	0	A	d
1938, June 25	23:45:08	77 N.	8 E.	B	d

the Russian workers have had access to original seismograms, and have also included epicenters determined by their own seismological service. Even the smaller number of epicenters on Figure 11 suffices to show the general course of the active belt. Shocks have been felt on Spitsbergen and Jan Mayen, while Iceland has a long history of destructive earthquakes.

Although no epicenters are known between a point near the north end of Lake Baikal and those near the mouth of the Lena, it is reasonable to expect that future shocks may occur in this gap. The Lena active region

is on the commonly accepted boundary between the Angara stable shield and the structures of northeastern Siberia.

ATLANTIC BELT

The earliest systematic collection of data on Atlantic shocks is contained in the papers on seaquakes by Rudolph (1887; 1895). Shocks are felt on shipboard in the Atlantic chiefly near the Azores and in the central area near the equator. During the following 20 years it was found that comparatively few of these shocks were recorded by the instruments then in service in Europe and America. This showed that the activity reported by vessels must consist of comparatively small earthquakes, and it was suggested that much of it might be due to submarine volcanism. This is pretty certainly false; for with improved instruments epicenters began to be located in the Atlantic, and the energy of the shocks, though moderate, is still larger than that of any known volcanic disturbance. Sieberg and others had pointed out the association of seaquakes with the Mid-Atlantic Ridge; and Tams (1927a; 1928), using revised epicenters from the International Summary supplemented by other observations, showed that the Ridge is the chief locus of Atlantic seismicity.

The shocks in Figure 12 are largely different from those used by Tams, but the agreement with his results is very good. North Atlantic shocks are very favorably placed for epicentral determinations using the stations in Europe and North America; this is already less true of the equatorial active line, and is not true at all for the South Atlantic.

The Mid-Atlantic Ridge is not a mere rise or swell in the ocean bottom, but is shown by soundings to have a very complicated topography (Wüst, 1939a); it is in fact a submarine mountain range, as might be expected from the seismic activity following it. To the north it continues into the polar area.

The seismic belt has a branch passing eastward through the Azores, following their structural trend, (Wüst, 1939b) and presumably connecting with the Mediterranean active area. On the other side, there is no sign of seismicity between the Mid-Atlantic Ridge and the West Indies.

In the equatorial Atlantic the Ridge has a striking flexure, giving it a long nearly east-west course; this is faithfully followed by the seismic activity, which is higher here than elsewhere along the belt. This bend parallels the strong curves in the coasts of Africa and South America.

To the south the extensions of both the Ridge and the seismic belt are less definite. Tams (1931) suggests drawing the lines round the south of Africa into the Indian Ocean, which would connect with the active belt of that region. This possibility cannot be rejected, but others are equally likely. The small number of located epicenters in the South Atlantic is partly due to a real falling off in seismicity, as well as to the increased difficulty of location.

TABLE 17.—*Additional earthquake epicenters in the Atlantic Ocean*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1927, July 31	20:59:02	65½ N.	19 W.	D	d
1924, Sept. 4	16:01:16	64½ N.	23 W.	C	d
1929, July 23	18:43:08	64 N.	23 W.	B	c
1929, Dec. 15	01:33:26	63 N.	36 W.	C	d
1921, June 30	02:10:13	61½ N.	33 W.	C	d
1924, Dec. 12	02:20:57	56 N.	33 W.	C	d
1921, Aug. 23	05:11:57	57 N.	34 W.	C	d
1920, Feb. 7	11:50:36	56 N.	34½ W.	C	d
1930, April 16	13:44:50	55 N.	34½ W.	C	d
1929, July 4	07:56:42	56 N.	35½ W.	C	d
1929, March 3	16:52:02	56 N.	35 W.	C	d
1924, March 22	13:08:52	55 N.	34½ W.	C	d
1923, Sept. 30	01:20:50	54 N.	32 W.	B	c
1927, July 6	00:03:48	53 N.	34 W.	B	d
1923, Nov. 28	00:34:23	54 N.	37 W.	C	d
1922, Feb. 16	02:51:15	48 N.	28 W.	C	d
1926, Sept. 23	15:11:14	45 N.	29 W.	C	d
1923, July 18	01:06:03	42 N.	29½ W.	B	d
1923, July 18	06:02:19	43 N.	29½ W.	B	d
1921, April 22	16:04:02	44 N.	17 W.	C	d
1930, May 21	22:09:07	43 N.	30 W.	B	c
1924, Aug. 27	22:23:57	41½ N.	30½ W.	C	d
1926, April 5	23:29:19	39 N.	29 W.	B	c
1926, July 9	15:05:34	38 N.	30 W.	C	d
1926, Aug. 31	10:40:08	38½ N.	28 W.	A	d
1926, July 31	18:09:53	35½ N.	36 W.	B	c
1930, Oct. 21	19:05:51	36½ N.	23 W.	C	d
1929, April 21	12:37:52	34 N.	38 W.	B	d
1926, Jan. 7	14:31:18	33 N.	40 W.	A	c
1928, Aug. 15	15:38:48	32½ N.	43 W.	C	c
1930, March 7	06:41:00	32 N.	11½ W.	C	d
1923, May 31	22:06:03	32 N.	41 W.	B	d
1927, March 6	01:33:40	27 N.	45 W.	C	c
1920, Aug. 12	06:21:01	25 N.	46 W.	C	d
1925, Aug. 12	06:58:45	24 N.	46 W.	A	c
1924, Oct. 14	05:00:19	24 N.	45 W.	A	c
1922, Jan. 9	05:09:34	24 N.	46 W.	A	c
1928, Sept. 14	08:02:02	22½ N.	45½ W.	C	d
1930, Feb. 28	00:57:56	15 N.	46 W.	A	d
1929, July 6	09:46:15	14½ N.	46 W.	A	c
1925, July 5	07:02:09	13½ N.	42½ W.	B	c
1927, Sept. 3	19:47:45	11 N.	44 W.	A	b
1925, Oct. 13	17:40:34	11 N.	42 W.	A	b
1928, Dec. 10	15:39:00	9 N.	39 W.	C	d
1929, July 27	12:53:12	9 N.	40 W.	C	d
1928, Aug. 31	05:14:34	8 N.	37 W.	C	d
1929, Jan. 27	16:07:12	8 N.	37 W.	B	c

TABLE 17—*Concluded*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1923, Sept. 26	02:29:20	1½ N.	29½ W.	C	c
1923, Aug. 8	12:17:25	½ N.	30 W.	C	c
1920, Nov. 12	05:41:38	1 N.	28 W.	B	c
1924, June 20	16:21:34	0	26 W.	C	d
1920, Dec. 5	10:01:15	0	17 W.	B	d
1929, Jan. 18	21:27:45	1 N.	17 W.	B	d
1928, May 12	20:28:00	1 N.	19 W.	B+	c
1928, Sept. 18	17:19:20	0	20 W.	B	c
1929, March 31	03:09:53	1 S.	15 W.	C	c
1925, Aug. 20	23:04:30	1 S.	21½ W.	C	c
1925, Sept. 12	14:14:58	1 S.	19 W.	C	d
1929, June 5	10:50:11	1 S.	14½ W.	A	c
1924, Oct. 12	19:34:10	½ S.	29 W.	B	c
1923, July 20	15:02:37	1½ S.	13½ W.	B	c
1929, Feb. 2	00:00:19	1½ S.	21 W.	A	b
1920, July 4	00:11:40	2 S.	14 W.	C	d
1928, Aug. 3	11:44:42	2 S.	14 W.	B	c
1929, Aug. 22	19:40:53	3 S.	21 W.	C	c
1922, Nov. 8	23:33:45	6½ S.	11 W.	C	d
1928, April 3	16:42:45	11½ S.	14½ W.	B	c
1926, May 17	21:42:17	14½ S.	14 W.	C	c
1929, July 25	22:57:17	13½ S.	14 W.	B	c
1925, Dec. 15	10:31:31	25 S.	9 W.	C	c
1925, June 13	20:23:10	29 S.	22 W.	B	c
1930, Dec. 25	13:07:19	33 S.	13 W.	C	c
1928, Nov. 22	08:31:01	56½ S.	3 W.	B	c
1920, Sept. 4	14:09:02	55 S.	2 E.	C	c
1927, Nov. 14	15:04:35	54 S.	8 E.	B	c
1928, July 19	23:38:45	55½ S.	9 E.	B	c
1935, Feb. 6	01:53:56	31 N.	42 W.	B	c
1938, Feb. 15	03:27:42	19 N.	26 W.	A	c
1939, May 8	01:46:50	37 N.	24½ W.	A	b
1939, June 5	23:03:31	36 N.	34½ W.	C	d
1939, June 22	19:19:31	6 N.	1 W.	A	c
1937, Aug. 22	11:31:44	7 N.	36 W.	B	c
1937, Oct. 6	21:48:02	1 N.	29 W.	C	c
1937, Dec. 28	06:19:26	1 N.	29 W.	B	c
1937, Dec. 13	22:58:47	26 N.	45 W.	C	d
1938, March 1	23:26:58	55 S.	12 E.	B	c
1939, Aug. 2	00:46:22	36 S.	16 W.	B	c

INDIAN OCEAN BELT

A seismic belt, in many respects similar to the Arctic-Atlantic belt, passes through the western Indian Ocean. Maps by Tams (1931) and other investigators carry no suggestion of such a line; they indicate only a few isolated epicenters in the whole area. The belt first appears plainly

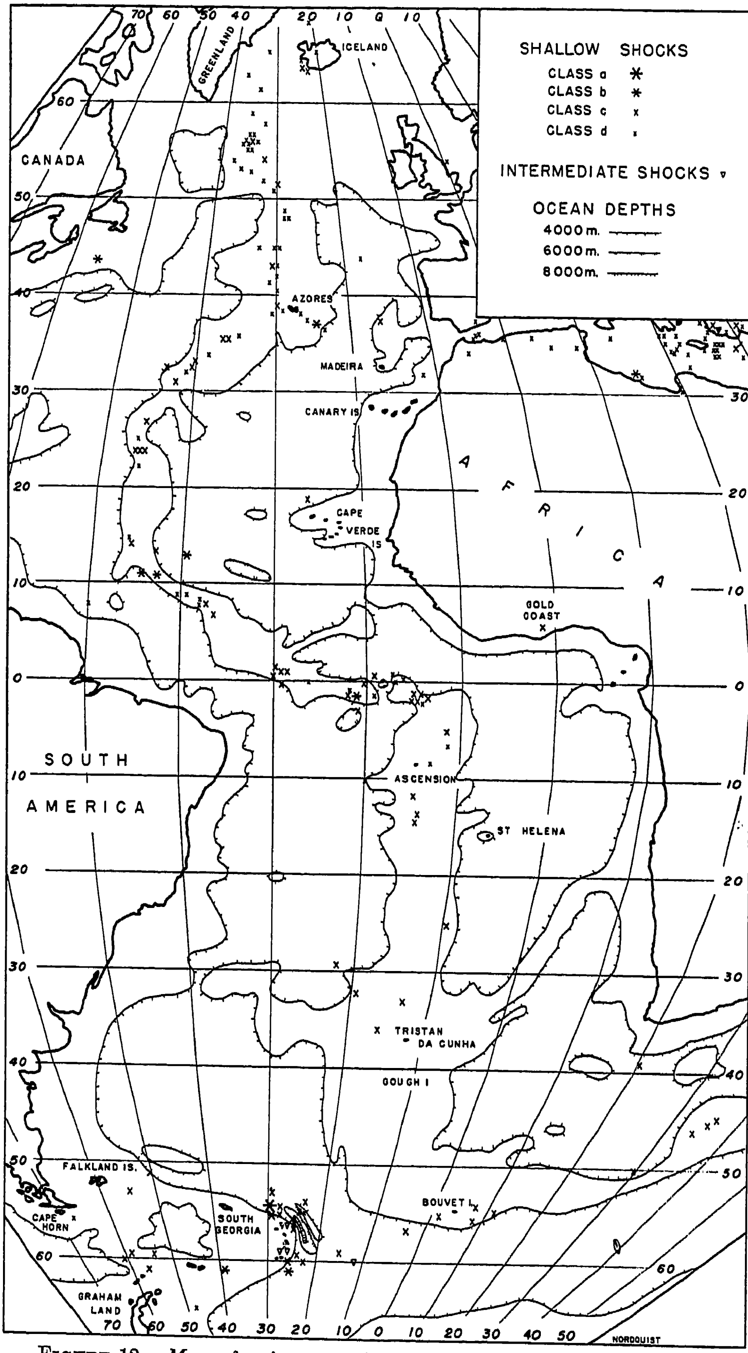

FIGURE 12.—*Map of epicenters, Atlantic and western Mediterranean*

TABLE 18.—*Additional earthquake epicenters in the Indian Ocean*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, April 28	04:58:44	14½ N.	53 E.	B	d
1928, March 19	10:02:06	14½ N.	53½ E.	B	d
1924, April 20	14:27:04	15 N.	52 E.	B	c
1929, March 16	12:30:52	14 N.	52 E.	C	d
1928, Sept. 18	19:52:37	14 N.	52 E.	A	c
1923, Dec. 10	23:53:38	13½ N.	50 E.	C	d
1926, Jan. 5	10:03:24	11 N.	58 E.	B	d
1928, July 4	17:53:38	10 N.	57 E.	B	c
1929, Jan. 1	13:58:18	9½ N.	62 E.	C	d
1925, Feb. 2	18:44:31	9 N.	62 E.	C	d
1928, July 6	00:48:05	4 N.	62½ E.	C	c
1927, Aug. 18	01:50:55	5 N.	63 E.	C	d
1930, Aug. 23	15:07:40	6 N.	65 E.	C	d
1926, Dec. 2	16:41:47	1 N.	67 E.	C	d
1923, May 28	01:25:53	1½ S.	88½ E.	B	c
1926, Jan. 18	21:07:23	2 S.	89 E.	B	c
1928, Feb. 7	00:01:43	2½ S.	88½ E.	A	c
1928, March 9	18:05:27	2½ S.	88½ E.	A	b
1930, March 9	08:52:26	3 S.	71 E.	C	d
1922, Sept. 8	14:14:13	2½ S.	68 E.	C	d
1922, July 3	05:29:22	8½ S.	66 E.	B	c
1929, Feb. 17	20:44:17	8½ S.	67 E.	C	d
1929, May 5	16:56:43	13 S.	66 E.	B	d
1922, Feb. 14	12:45:22	13½ S.	67 E.	C	d
1925, July 8	04:56:02	14½ S.	67 E.	C	d
1928, Oct. 25	12:36:19	13½ S.	68½ E.	C	d
1926, Dec. 24	07:01:10	19 S.	65 E.	C	d
1923, Nov. 26	12:18:37	31 S.	58 E.	C	d
1930, April 27	14:26:22	33 S.	59 E.	B	d
1925, April 11	10:42:02	34 S.	59 E.	B	b
1925, May 3	22:59:04	34 S.	58 E.	B	b
1925, May 19	05:23:45	33½ S.	58 E.	B	b
1925, May 28	05:55:11	35 S.	56 E.	C	c
1925, July 7	08:14:02	35½ S.	59½ E.	C	c
1925, Oct. 12	05:44:40	34 S.	60 E.	B	c
1926, March 21	12:05:58	34 S.	58½ E.	C	c
1926, May 31	13:35:49	33½ S.	57 E.	B	c
1926, Sept. 2	01:21:52	33½ S.	59 E.	B	b
1926, Dec. 2	08:13:44	34 S.	57 E.	C	c
1927, March 21	15:05:34	33 S.	58 E.	B	c
1927, April 11	22:03:50	34 S.	59 E.	C	c
1927, April 16	09:11:10	33½ S.	58½ E.	C	c
1927, Sept. 10	16:28:15	34 S.	57 E.	C	c
1927, Oct. 19	13:48:40	34 S.	59 E.	C	c
1927, Nov. 8	03:10:28	34 S.	60 E.	A	c
1928, Jan. 30	03:15:24	33 S.	59 E.	B	c

TABLE 18—*Concluded*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1928, March 27	19:06:48	34 S.	60 E.	C	c
1928, Aug. 8	02:15:14	34 S.	57 E.	C	c
1928, Nov. 11	22:40:56	34 S.	58 E.	C	c
1929, Jan. 8	07:23:27	33 S.	60 E.	C	c
1929, April 9	03:52:49	33½ S.	58 E.	C	c
1929, May 3	08:08:37	33 S.	60 E.	C	d
1929, June 6	14:18:53	33½ S.	59 E.	C	c
1929, Sept. 10	20:22:40	34 S.	60 E.	C	c
1930, Jan. 17	11:10:19	33 S.	59 E.	C	c
1920, Dec. 4	05:51:47	39 S.	21 E.	C	c
1927, Oct. 15	10:59:10	41 S.	47 E.	C	d
1924, Dec. 11	17:28:34	41 S.	80 E.	C	d
1928, May 31	23:23:58	41½ S.	80 E.	C	c
1927, Oct. 16	14:12:08	44 S.	42 E.	C	c
1928, March 17	14:22:09	44 S.	43 E.	C	c
1927, Jan. 29	18:37:37	44 S.	37 E.	C	c
1924, Aug. 25	02:21:45	45 S.	35½ E.	B	c
1926, May 9	09:47:37	46 S.	34 E.	C	c
1924, Feb. 29	08:38:20	50 S.	30 E.	C	c
1938, Oct. 21	20:24:12	2½ N.	66 E.	B	c
1938, Oct. 23	15:01:10	17 S.	42 E.	C	c
1936, March 21	01:52:11	17 S.	66 E.	B	c
1937, Aug. 20	06:38:05	26 S.	67½ E.	B	c
1938, Sept. 10	22:23:57	7½ N.	79 E.	A	d
1938, May 8	13:48:00	48 S.	99 E.	B	c
1939, March 21	01:11:09	1½ S.	89½ E.	B	c
1939, May 23	04:18:45	9 N.	59 E.	B	c
1929, Aug. 16	21:28:25	16½ S.	121 E.	C	c
1936, Aug. 23	20:45:58	3 S.	67 E.	C	d
1939, Feb. 8	10:26:40	10½ S.	66 E.	C	d
1939, July 16	12:21:33	15 S.	65 E.	C	d
1939, Aug. 7	23:59:42	4 N.	77½ E.	B	d

in maps based on the later years of the International Summary. Figure 13 (also Fig. 5) is still clearer; epicenters (principally from Table 18) depend in large measure on observations at Tananarive (Madagascar) and at Bombay.

The belt runs through comparatively shallow parts of the ocean, along a series of ridges and rises which occasionally emerge into banks and islands. Here and there this series appears to be interrupted by deep channels and basins. However, the bottom of the Indian Ocean is still very imperfectly mapped. The 4000 meter contour in Figure 13 is drawn in conformity with Vaughan, *et al.* (1940). Wüst (1934; 1939a; 1939c) points out that

temperature distribution suggests a division of the Indian Ocean below 4000 meters into two regions separated by a continuous barrier extending from the Mascarene Islands to the Kerguelen Ridge north of Amsterdam Island.

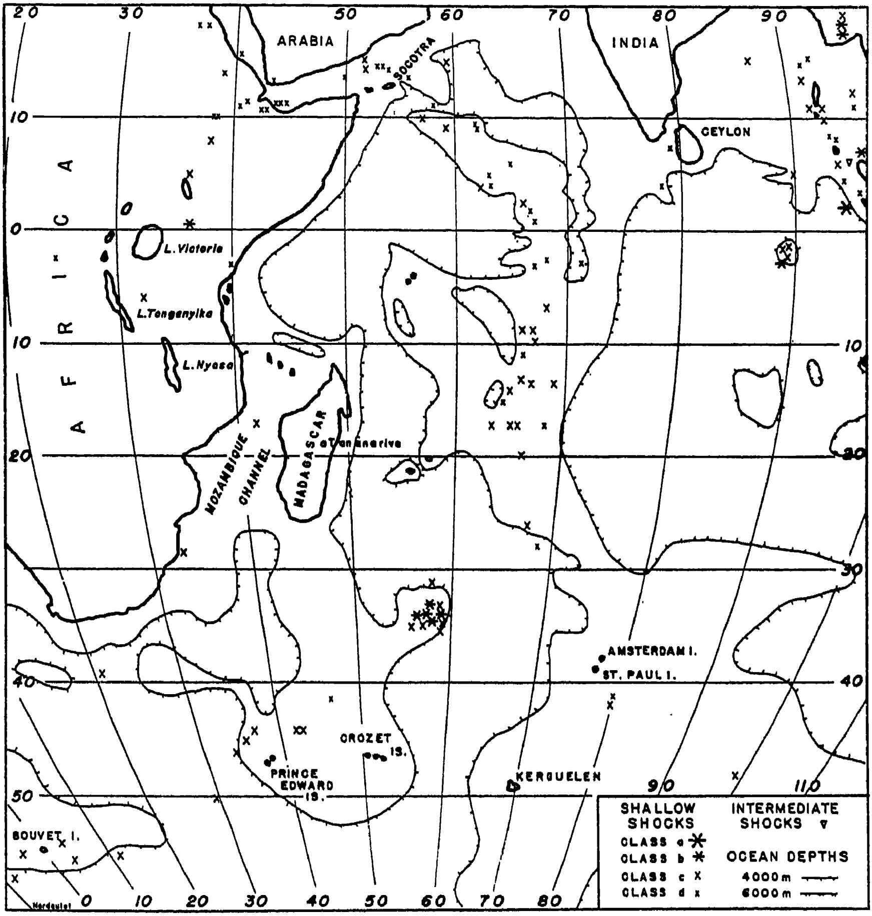

FIGURE 13.—*Map of epicenters, Indian Ocean and east Africa*

The main seismic belt begins abruptly off the coast of Arabia north of the island group of Socotra. The trend is roughly southeastward along the ridge discovered by Schmidt and called the Carlsberg Ridge, which has been confirmed recently by the work of the John Murray Expedition (Farquharson, 1936; review by Hoffmeister, 1938). Near the equator the belt changes direction rather sharply (this is as apparent on a globe as on Fig. 13), and continues west of south. About 30° S. 65° E. the prevailing

depths are greater than 4000 meters and there is a gap in the seismic belt. With increasing south latitude locations become more difficult, nevertheless the seismic belt is easier to follow than that in the South Atlantic.

It was not practicable to map each individual shock near 34° S. 57° E., listed in Table 18. This accumulation of epicenters partially represents a period of seismic activity which is important in evaluating the probable relation of a study like the present to the summed-up seismicity of the world over a period of several centuries. The first known shock of this group took place in 1925; there followed a long series, with some interruptions, until 1933. Many of these shocks were strong enough to register well at distant stations, though none of them were larger than our class *b*. Since 1933 the principal activity of the belt has been at other points. In the International Summary all these shocks are referred to one epicenter at 34° S. 57° E.; but the data are sufficient to justify a distribution over a more extended area. This is confirmed by the appearance of the seismograms at Tananarive (Poisson, 1939, p. 111). The few epicenters north and west of Prince Edward Island, and near Bouvet Island, suggest a westward continuation of the active belt, which apparently continues to join the South Antillean loop, already discussed as part of the circum-Pacific belt.

A minor seismic belt along the general trend of Wüst's barrier would include the fairly well-located epicenters near 41° S. 80° E. (1924, 1928) and possibly an unmapped shock on February 20, 1940, at 13:54, tentatively located near 38° S. 79° E. It would also include the well-located shock at 48° S. 99° E. (May 8, 1938) and might be expected to reach the Macquarie Island loop at its northwestern limit.

In the northeast corner of Figure 13 is the active arc of the Andaman Islands. Southwest of it is a peculiarly isolated group of shocks. Our knowledge of the seismicity of this part of the globe is still imperfect. On November 19, 1906 a strong shock (class *b*) was felt from Albany to Sharks Bay—that is, along almost the whole west coast of Australia—and as a seaquake near 21° S. 105° E. (Szirtes, 1910). The readings are not very consistent, but indicate an epicenter near 20° S. 110° E. much to the north of that given by Szirtes. The enormous disturbed area suggests focal depth of about 50 km. A strong shock (magnitude 7?) near 30° S., 115° E., on April 29, 1941, at 1:53.7 was felt throughout the Southwestern Division of Western Australia.

EAST AFRICAN RIFTS

The active belts of East Africa differ from those just discussed, in being associated with interior fractures of a continental mass, instead of being marginal or oceanic phenomena. Their seismicity is higher than that of any other such structures, excepting possible analogies with parts of the Asiatic active zone. However, the African activity is very moderate, even

compared with the Atlantic and Indian Ocean belts, which in turn are much less active than the Pacific and Asiatic belts. It has been difficult to extract from the available seismometric data the small group of fairly well-determined epicenters included in Table 19 (Fig. 13). The years just

TABLE 19.—*Additional earthquake epicenters in East Africa*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1921, Aug. 14	13:15:28	15½ N.	40½ E.	C	d
1921, Sept. 21	11:01:31	14 N.	39 E.	C	d
1926, Oct. 30	01:38:10	11 N.	44 E.	C	d
1929, Jan. 22	14:43:05	11½ N.	43½ E.	B	d
1930, Oct. 27	23:28:41	12½ N.	43½ E.	C	d
1929, May 18	01:02:12	11½ N.	41½ E.	B	d
1930, Oct. 25	17:41:55	11½ N.	44 E.	C	d
1930, Oct. 24	10:47:21	10½ N.	43 E.	C	d
1928, Oct. 4	18:22:58	7 N.	38 E.	B	c
1928, Jan. 6	19:31:58	½ N.	36½ E.	A	b
1929, July 26	17:18:50	2½ S.	24½ E.	C	d
1919, July 8	21:06:25	6 S.	32½ E.	B	c
1938, July 21	09:10:42	3 S.	40 E.	B	d
1938, May 12	21:31:32	18 N.	37½ E.	B	d
1938, Sept. 27	02:31:49	11 N.	41 E.	C	d
1939, Jan. 23	02:22:53	32 N.	16 E.	A	d
1938, Oct. 20	13:14:58	10 N.	38½ E.	C	d
1938, Oct. 23	02:25:14	10 N.	38½ E.	C	d
1937, Nov. 30	12:57:46	5 N.	36 E.	B	c

preceding the higher development of precise seismometry were a period of greater activity in East Africa than any time since. The shock of December 13, 1910, has been dropped from the list of great earthquakes (magnitude 7½ ?); it was felt over a very wide area, and was strong in the vicinity of Lake Tanganyika. (*See* Sieberg, 1932a, p. 883.)

The complexity of the known rift structures is reflected in the seismicity, which is not confined to any single narrow line in the equatorial region. A seismic belt runs northeast through Ethiopia to the head of the Gulf of Aden. There is also activity along the west coast of the Red Sea; but the seismological evidence does not indicate any continuous active line drawn from central Africa across Suez into the unquestionably active Jordan trough of Palestine. (Note the destructive Palestine earthquake of July 11, 1927 on Figure 10.) Any such projection of the African rifts must be based on geological and geomorphological evidence. The occasionally encountered assertion, that there is a seismically active belt following such a course, is based on papers published in an earlier epoch of seismology.

THE STABLE MASSES

GENERAL STATEMENT

To this point the description has covered the active belts and areas. The present section takes up certain large areas which are nearly free from shocks. Only the larger and more important masses of this type have been selected for detailed discussion; stable areas of all sizes exist, their number increasing as one proceeds to smaller dimensions. Even in the interiors of the most active belts it is possible to find minor crustal blocks which are internally unfractured, and are disturbed only by earthquakes external to them. The trans-Asiatic zone includes many such blocks, some of which are hundreds of miles wide.

Of the principal stable masses that of the Pacific basin differs structurally from all the others. The remainder are principally continental nuclei, continental shields, or oldlands, which remain as nearly undisturbed at present as they have been through most of their geological history. A few smaller blocks of similar type will be mentioned, owing to their significance in connection with the general pattern of world seismicity.

Nearly all the stable masses exhibit a few marginal or internal fractures which are seismically active.

PACIFIC BASIN

The Pacific basin is the largest of all the stable masses. Except for the single internal zone of the Hawaiian Islands, and for possibly volcanic shocks in some other island groups, it is an area of complete seismic calm. This is particularly well established for the north Pacific.

The outline of the stable area is evident from the world maps (Figs. 1, 2, 15). Almost no epicenters fall within the Pacific basin, away from the surrounding active belts. Rare exceptions may occur; the best established is the shock of January 4, 1933, off the North American coast at 28½° N. 127° W., but the boundary of the Pacific basin in that sector is not definitely known.

Seismological maps sometimes show epicenters at scattered points interior to the Pacific basin. Especially in its earlier years, the International Summary contains epicenters for poorly recorded shocks which were located, often with expressed doubt, in the stable area. All these epicenters have been subjected to close critical examination. It can now be stated positively that not one of these is well established; many of them are seriously in error.

These shocks will now be discussed in detail, excluding many supposed epicenters near the margin of the stable area; moderate error in these would admit of their being ordinary shocks in the adjacent active belts. Such error has often been found, and not rarely a more usual epicenter could be assigned. Some of these curious cases are deep-focus earth-

quakes, located erroneously on the supposition of normal focal depth. Others are simply inadequately recorded, or too much weight has been placed on the data of one or two stations with inferior instruments.

The following discussion includes only the 18 shocks, which the International Summary places well out in the Pacific basin. Hawaiian shocks are omitted. Shocks are given in order of latitude from north to south. Accurate location is out of the question unless several stations in different directions from the epicenter have recorded P, the first seismic motion; it is usually difficult and doubtful without several consistent readings for S. Other readings, referring usually to reflected waves and surface waves, are of little use in finding the epicenter; these will be noted as "late readings."

43° N. 170° E. Oct. 6, 1921, 15^h. P and S at Mizusawa and Eskdalemuir give origin time 2 minutes later than in the Summary and a very different epicenter. S at other European stations may be a late phase. Possibly deep focus; perhaps an intermediate shock in the Kurile Islands.

40.5° N. 160.5° E. Aug. 27, 1927, 12^h. Usefully recorded at seven stations. The given solution roughly fits Zi-ka-wei, Irkutsk, Baku, and Tiflis but not Ekaterinburg and Tashkent. Ootomari reports a time which is much too early to fit, and Mizusawa appears to begin 2 minutes late. It is impossible to tell which data are correct.

40.5° N. 160.5° E. April 21, 1930, 21^h. Nine stations, three with no P. The solution fits only Zi-ka-wei and Baku, and is marked *X*, which means that "there is much uncertainty as to even the approximate origin."

34° N. 162° W. June 17, 1917, 08^h. Five stations; only one P, no S. Melbourne flagrantly inconsistent. No evidence for the indicated epicenter.

30° N. 174° W. Oct. 1, 1918, 00^h. "Very unsatisfactory." A badly forced solution. P and S only at Tokyo, except that a surface wave reported at Honolulu for the next hour (when there was also a shock) is assumed to be P with an error of 1 hour, though it still comes out 58 seconds early.

26.8° N. 172.0° E. Oct. 11, 1928, 23^h. Two shocks, 12 minutes apart. Epicenter by the Russian stations, does not fit well. More probably Aleutian Islands near 52° N. 175° E.

16.0° N. 153.5° E. May 14, 1923, 02^h. Four stations, only two with P. "Very rough." Data insufficient.

12.5° N. 168.0° E. Sept. 19, 1923, 08^h. P only at Osaka. The solution fits only a small part of the data. Possibly in the Tonga salient.

11.7° N. 176.0° E. May 21, 1918, 11^h. P and S at Riverview; S at Manila. Other stations have only late readings. May be anywhere in the Pacific area.

9° N. 155° E. May 16, 1925, 10^h. Eastern Caroline Islands. Depends on Manila, Riverview, Batavia, and Ekaterinburg and cannot be rejected definitely; to bring it into the active belts would require an error of 10 or more degrees.

9° N. 155° E. Sept. 29, 1926, 05^h. Two shocks. "Very rough indeed." Almost all data are late readings and many do not fit.

9° N. 155° E. March 3, 1928, 17^h. Tashkent and Ekaterinburg have P and S in rough agreement with the given solution. Manila and Zi-ka-wei do not fit. Other stations have only late readings. Data insufficient.

5° N. 148° E. Jan. 21, 1920, 06^h. Fitted to P and S at Riverview. Readings at other stations are imperfect, and none of them fit, except a possible S at Batavia.

1° N. 129° W. June 17, 1924, 20h. Depends on P and S at Tacubaya and La Paz, S at Toronto and a few late readings. The data hardly suffice.

1° N. 129° W. November 25, 1927, 19h. Depends on La Paz, Tucson which has P and S half a minute late, and a few late readings. The data are insufficient, and certainly include errors.

3.0° S. 177.5° W. Feb. 10, 1921, 19h. Fitted to P and S at Apia and Riverview, with S at Wellington, Adelaide, and probably Melbourne. Apia had suggested 26° S. 176° W., which does not fit the other data. Doubtful, but may be correct.

3.0° S. 177.5° W. Nov. 28, 1927, 10h. "Very uncertain." P and S at Apia and Suva, with late readings elsewhere. May be in the Tonga salient.

3° S. 172° W. Dec. 24, 1929, 04h. "Very uncertain," pointing out that the solution depends on P and S at Apia and Suva; P at Sydney and S at Adelaide. Too much weight is given to Suva, and the other data are difficult to reconcile.

7° S. 178° E. Oct. 21, 1928, 15h. Depends on Apia and Suva, which disagree. Readings at Apia indicate an epicenter close to Apia, and suggest time error at Suva. Other stations have only late readings.

22° S. 141° W. June 21, 1918, 3h. "Clearly defective." Only P and S at La Paz fit. Readings at other stations are so late that they probably refer to a different shock.

None of these interior Pacific epicenters are found in the International Summary after 1930. Most of those listed above are taken from the earliest years, when earnest but often fruitless efforts were made to locate any shock reported by a few stations. These examples are representative of the type of data rejected throughout the present study, in all parts of the world, and regularly referred to as "small and imperfectly recorded shocks."

The epicenter at 9° N., 155° E., apparently represents one actual shock outside the active belts and may perhaps be correlated with a reference by Sieberg (1932a, p. 919) to a shock on April 11, 1911, which was strong on Ponape, in the eastern Carolines near 7° N. 158° E. De Ballore (1906, p. 174) refers to shocks felt at Tahiti and in the Society Islands. A class *d* shock occurred on June 20, 1938, 14:02.5 near 6° N. 119° W.

Although the earthquakes of the Hawaiian Islands occur in an active volcanic region, and a large proportion of the numerous small shocks on the main island of Hawaii are undoubtedly direct results of volcanic processes going on comparatively near the surface, there are other larger shocks which must be considered as tectonic in origin. The most noteworthy is the great shock of April 2, 1868 (Wood, 1914; 1933). Though this was accompanied by eruptive phenomena on Hawaii, it produced fracturing at the surface such as might result from the displacement of large underlying masses of magma, or solid material, or both. Moreover, it presumably originated at the depth usual for great earthquakes, for it was not only violently destructive in the southern part of the island of Hawaii, but was moderately strong at Honolulu, and apparently perceptible on all the islands of the group. It was preceded and followed by many other small shocks.

In the middle of September 1929 a swarm of small shocks began in the northwestern part of the Island of Hawaii near the dormant volcano Hualalai, which erupted last in 1802. Larger shocks occurred; that of September 26, at 04^h, was recorded as far as western Europe. The largest shock of the group (magnitude $6\frac{3}{4}$) took place on October 6, at 07^h. There were effects of much violence, and extensive damage, in the Kona district, which includes Hualalai. The seismograms are of the usual character for shallow earthquakes. The International Summary gives for these two larger shocks an epicenter, on the east coast of Hawaii, but the data agree very well with the macroseismic epicenter at Hualalai near 19.8° N. 155.9° W. No eruption was associated with this group of shocks.

Two shocks of about the same magnitude occurred on January 23, 1938, at about 21° N. 156° W., and on June 17, 1940, 10:26:47 at $20\frac{1}{2}$° N. $155\frac{1}{4}$° W. Honolulu, as in 1871 and 1881, occasionally has been heavily shaken by earthquakes which were not so strong elsewhere in the islands.

CANADIAN SHIELD

The writers' use of terms like the Canadian Shield is geographical, and is not meant to express preference for any particular interpretation in terms of historical geology. The term "Laurentian Shield" might be preferable; the reference is to that large part of Canada, with a small area in the United States, over most of which the pre-Cambrian rocks of the Laurentian series are exposed at the surface.

The interior of the Canadian shield, thus defined, appears to be completely aseismic. Because of the proximity of good stations it is sure that only minor shocks could have escaped notice. However, the marginal part of the shield is subject to occasional large shocks, with fairly frequent minor local disturbances. Of the four known larger shocks, three originated near the St. Lawrence River. These are the great earthquake of 1663, which was violent near Three Rivers (roughly $46\frac{1}{2}$° N. $72\frac{1}{2}$° W.), the large shock of March 1, 1925 (Feb. 28, 1925, local time) in the Saguenay River district at about 48.2° N. 70.8° W., and the moderate shock of October 19, 1939, at about 47.8° N. 69.9° W. The 1925 shock is No. S1 of the deep-focus list; however, the depth of 50 km. assigned to it is probably usual for this region and might be called "shallow." To these add the Timiskaming earthquake of November 1, 1935, near 46.1° N. 79.1° W.; this is No. S2, with depth estimated roughly as 80 km. It is doubtful whether the New Hampshire earthquakes of December 20 and 24, 1940 (44° N. 71° W.) should be included here or with the Appalachian shocks.

A second group of such marginal shocks is that of the Baffin Bay earthquake of September 20, 1933 (Table 4) and its aftershocks. It is a good instance of the occasional unexpected occurrence of a large shock in a region not previously considered to be active. Small shocks have often been reported felt on the west coast of Greenland (Tams, 1922) and Ter-

tiary faulting has been found there. (*See* Born, 1933, p. 800, following Koch, 1929). Whether the Baffin Bay shocks are considered interior or marginal depends on whether the pre-Cambrian rocks of Greenland are considered as part of the Canadian shield or as forming a separate block.

A third and northwestern group of marginal shocks are:

1920, Nov. 16	08:31.0	72½° N.	128° W.	B	c
1940, May 29	01:57.9	67° N.	135° W.	B	c
1940, June 5	11:01.3	67° N.	135° W.	B	c

South and west of the Laurentian area lies an extensive region which is fairly stable judged by geological criteria. However, shocks are known to occur there, and the region will be discussed in the next main section.

BRAZILIAN SHIELD

For a summary of Brazilian earthquakes refer to Branner (1912; 1920), who has also described the regional geology (Branner, 1919). In the Brazilian shield may be included the Archaean masses of Brazil and Guiana, together with later rocks consolidated with them by Palaeozoic folding. The shield then includes all South America east of the Andes and north of the Plata.

The shocks of this whole area are quite insignificant, never reaching destructive violence, and often perceptible only over small areas. They appear to be connected with ancient or minor structures within the stable mass. In spite of the records of good stations at Rio de Janeiro and La Plata, only one shock has yet been located in this area from instrumental data:

1939, June 28, 11:32.5, 27½° S. 48½° W. B d.

Not one sound instance appears in the International Summary. A number of epicenters in the Summary are in the western part of the shield; nearly all of these are probably misplaced Andean shocks, some of them being unrecognized instances of deep focus. The two groups of very deep shocks near 2½° S. 70° W. and 10° S. 70° W. are under the shield; but these are clearly part of the circum-Pacific activity.

On Figures 2 and 12 is an epicenter at 7° N. 38° W. (May 31, 1932; Table 3). This is definitely outside the Atlantic active belt, and appears to be marginal to the South American stable mass.

EURASIAN STABLE MASS

Figures 2 and 10 show a great blank including the Baltic shield of Europe, the Angara shield of Asia, and the intervening Ural mountain system. Throughout this vast area there is apparently no report of felt earthquakes, except that near its boundaries shocks of adjacent active zones are noticed, and that minor local shocks have occurred in the southern Urals. (*See* Mushketov, 1936a; Weiss-Xenofontova, and Popoff, 1940).

Still more definitely, there is not a single good instrumental epicenter; although a chain of first-class stations at Moscow, Baku, Sverdlovsk (formerly Ekaterinburg), Tashkent, Irkutsk, and Vladivostok was established under the imperial Russian government, and has been maintained by the Soviet government with the addition of important local networks in Crimea, the Caucasus, and central Asia. The few epicenters in this area given by the International Summary are as bad as those in the Pacific, or worse.

On the south and southeast the stable mass is bounded by the active belt of the central Asiatic highlands. In the northeast is the active area near the mouth of the Lena, which is at the end of the known extent of the Arctic active belt. Between these, the border of the Angara shield has shown no verifiable recent activity.

On seismological evidence alone the stable mass might be made to include the extreme northeastern part of Asia, east of the Lena and the Angara shield, excluding Kamchatka. Here the only known shocks are near the coast. Since this area appears to differ geologically from the stable masses, it is discussed in the next main section.

AFRICA

The huge African stable mass appears on Figures 12 and 13. Most of the epicenters shown are the result of systematic search, which has been carried out as carefully as for the Pacific basin.

The African rift zones have already been considered, and the shocks of the Mediterranean coast have been discussed with the trans-Asiatic zone. Between the equator and 30° N., outside of the Rift and Red Sea regions the International Summary lists only four small shocks, for which the data are either very scanty or very inconsistent.

The Summary locates two shocks at 3° S. 24° E. For one of these, in 1922, the data are insufficient even to establish the region of occurrence; this might be a misplaced Rift shock. The other, that of July 26, 1929, has been accepted with a slight shift in epicenter (Table 19). The location is not good, and the epicenter has been retained largely in order to have definite representation of the shocks which undoubtedly occur in this region west of the Rifts. For reports of shocks felt here *see* Sieberg (1932a, p. 879–881). These are our only seismological evidence of the separation between the units composing the African mass.

The long history of Egypt includes a few strong shocks which appear to have originated on the continent. Some of these are listed by Sieberg (1932a, p. 873; 1932b). The clearest cases of strong shocks are those of 1303 and 1847, apparently centering in the Fayum west of Cairo. The great shock of 1870 was probably an intermediate earthquake under the Mediterranean.

A few epicenters are mapped about the margins of Africa. In some cases

historical data support them. Strong shocks sometimes reported from the Canary Islands and Cape Verde Islands are in part volcanic; but one shock large enough to record at distant stations is known from each group. (Shocks of March 17, 1930 and Feb. 15, 1938; Table 17.) The destructive Gold Coast shock of June 23, 1939 (Table 17) is one of a series, of which that previously best observed occurred on November 20, 1906 (Junner *et al.*, 1941).

Off the south of Africa at 39° S. 21° E. is the shock of December 4, 1920 (Table 18). Just off the southeast coast at 28.5° S. 32.8° E. is the Zululand earthquake of December 31, 1932 (Krige and Venter, 1933). A shock of about the same magnitude originated in the interior, near 30° S. 25° E., on February 20, 1912 (H. E. Wood, 1913). The shock on May 19, 1940, 18:16.4 near 24° S. 31° E. (tentative), magnitude 7, strong in Zululand and Transvaal (Nature, June 8, 1940, p. 892) should also be noted.

In the Mozambique Channel is the epicenter of October 23, 1938 (Table 18). The Channel may be considered an internal fracture, as the stable mass of Madagascar is ordinarily taken as a detached part of the African mass. Only small shocks are known from Madagascar itself (Poisson, 1939). The epicenter at 3° S. 40° E. (July 21, 1938, Table 19) is on a branch of the Rift system.

ARABIA, INDIA, AND AUSTRALIA

The old stable mass of Arabia is nearly aseismic, with occasional marginal shocks; that on January 11, 1941, 8:32, is located tentatively at 17° N. 43° E. (Fig. 10). The undisturbed area includes most of Mesopotamia and eastern Syria. Epicenters of all but small recent shocks lie outside these areas. The historical record suggests occasional larger earthquakes, but these may belong to the active structures at no great distance to the east. The history of many shocks in Palestine and Syria supports the activity of the Jordan trough. For this and the single shock in Figure 10 (July 11, 1927; Table 14) *see* Sieberg (1932a, p. 796–803; 1932b) and Willis (1928, correction in 1933).

The oldland of peninsular India is not completely quiescent; the Indian stations report minor local shocks, and larger ones have occurred. The only associated shocks mapped in this study are marginal. The shock in the Bay of Bengal at 15° N. 87° E. (July 29, 1927; Table 13) may be in the epicentral region of the large shock of 1882, which was strong on all the coasts of the Bay. (*See* Doyle, 1882.)

The stable mass of western Australia also has its marginal shocks. That of November 19, 1906, was felt along almost the whole coast. Other earthquakes have been reported felt at Perth. On the opposite side of the stable mass, moderate and occasionally damaging shocks have occurred in the tectonically disturbed region of South Australia which extends

northward into the interior from the neighborhood of Adelaide. Only the following shock could be located:

1939, March 26	3:56:08	31° S.	138° E.	B	d

The International Summary contains no well-located continental Australian epicenters. Off the northwest coast is an epicenter (unmapped) at 16½° S. 121° E., August 16, 1929 (Table 18).

ANTARCTICA

The records obtained by the DISCOVERY expedition in 1902 have been discussed already. Teleseismic observation indicates that the whole of Antarctica is completely inactive. This fact has sometimes been obscured by vague references to shocks in "the Antarctic" which were actually in the Southern Antilles or the Macquarie Island loop. In both regions verifiable activity extends somewhat south of the 60th parallel.

The International Summary and its predecessor reports assign only 11 shocks from 1913 to 1930 and none since then to latitudes from 65° southward. These data have been reviewed with close attention. It was hoped that some of the results could be accepted, as in this part of the globe a single epicenter, established from instrumental data, would be of great significance, even though the location could not be specified within 10 degrees. However, none of these epicenters are satisfactory. The following notices are shorter than for the supposed shocks of the Pacific basin. The same general remarks as to importance of P and S, late readings, and so forth, apply. Nearly all these epicenters depend principally on reported times at La Paz for P and S. Other data are mostly doubtful and late readings. Most of these shocks might be in any of the active regions of southern latitudes.

65° S. 0° E. July 15, 1917, 10ʰ. Does not fit the data, not even the S at La Paz.

65° S. 0° E. June 16, 1921, 09ʰ. La Paz and a few late readings.

65° S. 39° W. May 20, 1920, 04ʰ. La Paz, doubtful S at Helwan, and late readings.

65.7° S. 50° W. Dec. 6, 1929, 11ʰ. Only four P's, all in South America. A revised solution gives 65° S. 47° W.; the epicenter depends delicately on the time of S at Tananarive. This is a southern member of the Southern Antillean group, but the location is inaccurate.

66.5° S. 170° E. Aug. 14, 1929, 02ʰ. "Very doubtful." P at five stations only. Comparison indicates an epicenter within a few degrees of that of Oct. 9, 1938, at 61° S., 160° E. (Table 9).

68° S. 90° W. Dec. 5, 1927, 17ʰ. P and S at La Paz and Sucre, S at La Plata, and late readings.

69° S. 10° E. Jan. 13, 1923, 09ʰ. La Paz, doubtful S at Riverview (reported as P), and late readings.

69° S. 108° W. Sept. 1, 1919, 19ʰ. La Paz, possibly S at Riverview and Melbourne, and late readings.

73° S. 120° W. March 22, 1917, 02ʰ. La Paz, and late readings in Europe.

75.5° S. 150° E. Oct. 15, 1920, 14^h. P and S at Riverview only. P readings at other stations have been taken as S, but still do not fit well. A few late readings

77° S. 11° E. Aug. 17, 1918, 10^h. La Paz, doubtful S at Riverview, and late readings.

No great shock (class *a*) can have occurred in the extreme south since 1904. Since about 1918 the International Summary provides assurance that a shock of class *b* could hardly have been overlooked or grossly misplaced. By definition, earthquakes of class *c* are well recorded up to 90°; such a shock at the south pole would be well recorded at all stations in the Southern Hemisphere. However, these stations are not numerous, and a combination of errors and accidents might result in the loss of such an epicenter. It might be possible to detect a shock of class *d* and identify it roughly as occurring in the south polar area.

Thus, Antarctica seems to be a stable mass comparable with those named above. It is not likely that an Antarctic seismological station would provide data that might modify this conclusion, since additional shocks most probably would fall into the minor classes, which are characteristic of major structures in other parts of the world. However, minor shocks in the Antarctic may prove to be better indicators of major structures and fractures than they are elsewhere.

OTHER AND MINOR STABLE MASSES

Of the areas usually named as continental stable shields there remains only that in eastern China. This is of smaller size than most of the others; it abuts against a very active region on the west and has marginal shocks in the coastal area to the east. One of the latter, on February 13, 1918 (Table 14) was destructive at Swatow. The Chinese block appears to be the largest of several such blocks internal to the trans-Asiatic zone, of which the next most important is that of the Gobi Desert

Among the important nonseismic areas of continental character should be included two oceanic areas. One is the Philippine Basin between the two main branches of the circum-Pacific belt. The other is that between the Easter Island Ridge and South America; its southern boundary is uncertain.

Still other undisturbed oceanic areas can be picked out from the maps. Of these, the Arctic Basin, north of Alaska, is probably an outlying area of Pacific structure. The shocks of 1920 and 1940 discussed with the Canadian shield are marginal to it.

Of the remaining land areas, Greenland is the largest stable mass; but it should perhaps be considered a detached part of the Canadian Shield. An important stable area includes Borneo, the Malay Peninsula, most of Indo-China, and the intervening China Sea. Three epicenters near Borneo are listed in Table 12. That at 7° N. 114° E. (July 21, 1930) may be either marginal or internal to the principal stable mass. Those inland from the east coast (April 19, 1923 and April 13, 1924) are clearly marginal. For macroseismic data *see* Sieberg (1932a, p. 833).

MINOR SEISMIC AREAS

GENERAL CONSIDERATIONS

Significant seismic activity is not altogether restricted to the principal active belts and the interior or marginal fractures of the stable masses. Two large areas, and several smaller ones are characterized by fairly frequent minor shocks and occasional larger ones. These areas necessarily fall between the stable masses and the active belts. The trans-Asiatic zone may perhaps belong in this classification, since it lies between the stable mass of northern Asia and the Alpide active structures. However, its shocks are larger and much more frequent than those of the other regions now discussed.

NORTH AMERICA

Previous discussion has covered the earthquakes of the Pacific coast and Caribbean region, and also the marginal shocks of the Canadian Shield. The remaining shocks of North America occur in the intervening area, which is included in the United States and northern Mexico. For the former, *see* Heck (1938b). The Mexican shocks in question occur in the structural belt which extends north through the United States in the Rocky Mountains, where there is moderate activity. Probably the largest known shock of this belt was destructive at Bavispe, in Sonora (Mexico), May 3, 1887. The larger shocks of recent years (magnitude $6\frac{1}{4}$ to $6\frac{3}{4}$) in this structural province were as follows:

1925, June 28	01^h	46° N.	112° W.	Montana
1928, Nov. 1	04^h	27° N.	$105\frac{1}{2}$° W.	Chihuahua, Mexico
1931, Aug. 16	11^h	30.6° N.	104.1° W.	Texas
1934, March 12	15^h	42° N.	$112\frac{1}{2}$° W.	Utah
1935, Oct. 19	04^h	$46\frac{1}{2}$° N.	112° W.	Helena, Montana
1935, Oct. 31	18^h	$46\frac{1}{2}$° N.	112° W.	Helena, Montana

The epicenter for the 1928 shock is revised, with origin time at 04:12:49, and quality C.

Earlier and smaller earthquakes demonstrate a general distribution of moderate seismic activity throughout this region, decidedly lower than that of the Pacific belt to the west of it (which includes the shocks of western Nevada and Owens Valley).

Minor earthquakes are fairly common in the southern Appalachian belt. Probably the largest of these in recent years, the Virginia earthquake of April 10, 1918, was of class *d* at best, as it was recorded only at the few nearer stations in eastern North America.

Near the Atlantic coast is the epicenter of the Charleston earthquake of 1886. The large area over which this shock was perceptible shows that it must have been of class *b*; while the effects near the epicenter were so comparatively moderate, and show so peculiar a distribution and relation to the geology, as to suggest intermediate focal depth, although that can hardly have been so much as 100 km. Other shocks in the same area have all been small.

Off the northeast coast is the Grand Banks earthquake of November 18, 1929 (class *b*, Table 4). Historical data suggest minor activity in the same region. This epicenter is near the edge of the continental shelf, which may here be determined by active structures.

Another exceptional disturbance was the group of earthquakes in 1811 and 1812 in the Mississippi Valley, not far from New Madrid (Missouri). One or more of these earthquakes must have been of magnitude 8 at least. Taking into account the enormous area disturbed and the violent effects near the epicenter, they must be ranked as the greatest shocks in the history of the United States. The structural relations of these shocks are not yet clear but the region is one of continuing minor seismicity.

Occasional notable shocks, still less frequent and in general smaller than those of the Appalachian belt, occur in the central United States.

NORTHEASTERN ASIA

The region of extreme northeastern Asia was not included in the Eurasian stable mass, largely for structural reasons. The geology of this area is little known; most authorities agree in limiting the Angara shield at the Verkhoyansk mountains in the region of the Lena River. This is the area terminal to the known extent of the Arctic active belt. No shocks are known in Siberia east of this district, except along the coasts. This of course should exclude the very active peninsula of Kamchatka, which is a mass belonging to the Pacific belt.

Figure 8 shows two epicenters on Sakhalin (Karafuto). The shock of 1924 was destructive on the island. Revision gives the following:

1924, March 15	10:31:22	49° N.	142½° E.	B	b

The other epicenter is that of July 10, 1932. Both shocks were shallow. This is important, because the region is one of frequent deep shocks (discussed with the circum-Pacific belt); these may account for other shocks felt in this region and in Manchuria west of it, where no shallow shocks have been located. The few other shallow shocks placed in this region in the Summary are either imperfectly recorded or are misplaced deep shocks.

At 56° N. 130° E. is the shock of January 22, 1939 (Table 4).

Two shocks (July 15 and October 10, 1931) are known from the epicenter at 59.3° N. 147.8° E., on the north shore of the Sea of Okhotsk.

An important epicenter (unmapped) is on the Arctic coast northwest of Bering Strait at 67° N. 172° W. The principal shock occurred on February 21, 1928, at 19:49:04 (revised; quality A, class *c*). Aftershocks from the same epicenter occurred on February 24 and 26 and on May 1, 1928. Not far to the east is another unmapped epicenter. Revision gives:

1926, July 14	22:22:25	66° N.	163° W.	C	d

This is on the north coast of Seward Peninsula, Alaska. It appears that

eastern Siberia and this part of Alaska are parts of the same structural and seismic province.

Purely coastal or marginal activity like this is characteristic of the stable masses, as well as of other minor seismic areas. However, any conclusions must be drawn with caution. Northeastern Asia is almost uninhabited, and there are no seismological stations near it. Seismicity comparable with that of most of northern Europe could not be detected there. Probably the region is analogous to the other areas discussed in the present section.

CENTRAL AND WESTERN EUROPE

The exceptional circumstances of our information about the seismicity of Europe call for special treatment. Figure 14 shows epicenters selected on principles not applied to the other regional maps. Within the limits of the map every reliable epicenter given in the International Summary for January 1931 to March 1934 has been plotted. This includes a number of minor shocks of class *e*, not otherwise considered.

A further list of epicenters (Table 20) resulted from a search through the International Summary and later bulletins for the large European shocks from 1918 to 1939. It contains only shocks well recorded out to 45° at least. The two Italian shocks of 1930 are of class *c*; the others are in the upper range of class *d*, with magnitudes probably all 6 or larger. Smaller shocks of class *d* in Figure 14 are as follows:

1931, April 24	15^h	31.1° N.	19.9° E.
1932, Jan. 2	23^h	39.0° N.	17.5° E.
1932, May 22	17^h	38.5° N.	15.0° E.
1932, Aug. 3	11^h	40.0° N.	19.5° E.
1933, March 7	14^h	41.1° N.	15.4° E.
1934, Feb. 4	9^h	41.4° N.	19.3° E.

African shocks shown on Figure 14, are from Table 15. All but two of these (1920, 1923) are comparable with those of Table 20. Almost all were reported strong or destructive on the African coast. The shock of April 19, 1935 on the coast of Libya, is far the largest shock of recent years in this region.

The shocks of Table 20 were destructive in the localities named. Epicenters for the first two have been revised; those following, down to 1933, are taken from the International Summary, and the later ones are approximately as given by the central office at Strasbourg.

The European area is divisible into several provinces of different character, some of which have been discussed in previous sections. In order of decreasing seismicity, these may be listed as follows:

(1) The Balkan and Aegean area.
(2) Italy and adjacent areas.
(3) The Rhine region.
(4) Great Britain, Scandinavia, and the North Sea.
(5) The remainder of western Europe.
(6) The Baltic shield.

The limits of the Balkan active area are roughly the meridian of 20° E. and the parallel of 41° N. (Fig. 10). This is a part of the trans-Asiatic zone, comparable with many other parts of it in seismicity. North and west of the indicated limits activity is far smaller. The northwestern

TABLE 20.—*Larger shocks in western Europe, 1918–1939*
Limits 37°–55° N., 5° W.–20° E.

Day	Time	Epicenter		Region
		Latitude, degrees	Longitude, degrees	
1920, Sept. 7	05^h	44 N.	10 E.	Carrara, Italy
1927, Feb. 14	03^h	43 N.	18 E.	Herzegovina
1928, March 7	10^h	38.6 N.	15.8 E.	Calabria, Italy
1928, March 27	08^h	46.5 N.	13.0 E.	Udine, Italy
*1930, July 23	00^h	41.1 N.	15.4 E.	Irpino, Italy
*1930, Oct. 30	07^h	43.6 N.	13.5 E.	Off Ancona, Italy
1930, Nov. 21	02^h	40.0 N.	19.5 E.	Albania
1931, June 7	00^h	53.8 N.	1.2 E.	North Sea
1933, Sept. 26	03^h	42.0 N.	14.2 E.	Abruzzi, Italy
1936, Oct. 18	03^h	46.2 N.	12.5 E.	Venetia, Italy
1938, March 27	11^h	45.8 N.	17.0 E.	Croatia
1938, June 11	10^h	50.6 N.	3.6 E.	Belgium
1939, May 20	09^h	41.1 N.	19.3 E.	Albania

* Of class *c*; all others of class *d*.

corner is in a quite active district, near the coast of Albania; two shocks in Table 20 fall close to it. Another shock, just to the east and consequently not mapped, was that of January 28, 1931, 05^h, at 40.1° N. 20.5° E., destructive at and near Koritza.

The Italian seismic area includes Italy and Sicily, the Adriatic, and the Dinaric mountains to the east. The activity is higher than that of northwestern Europe, but decidedly lower than that of the principal seismic regions. The two largest shocks of Table 20, in Italy, are still only of class *c*. The Messina earthquake of 1908 was approximately of magnitude 7, on the border between classes *b* and *c*. The area belongs to the Alpide zone, *Neo-Europa* of Stille. The shocks of North Africa and of the Betic mountains in southeastern Spain belong to the same group. So do the rare and minor shocks of the Pyrenees and southern France, from the geological point of view; the seismologist would rather group them under the slightly active regions of western Europe.

The shocks of the Alps are not easily included with the "Alpide" activity of Italy; they are smaller and less frequent. (*See* Wanner, 1934.) They are classified more naturally as members of the belt of epicenters extending northwest from Switzerland parallel to the Rhine structures, in the trend

of the Italian and Adriatic zone. This is a region of minor seismicity, such as would not even be noticed in general discussion if it were anywhere else. In a region like northeastern Asia, such activity would be quite unknown.

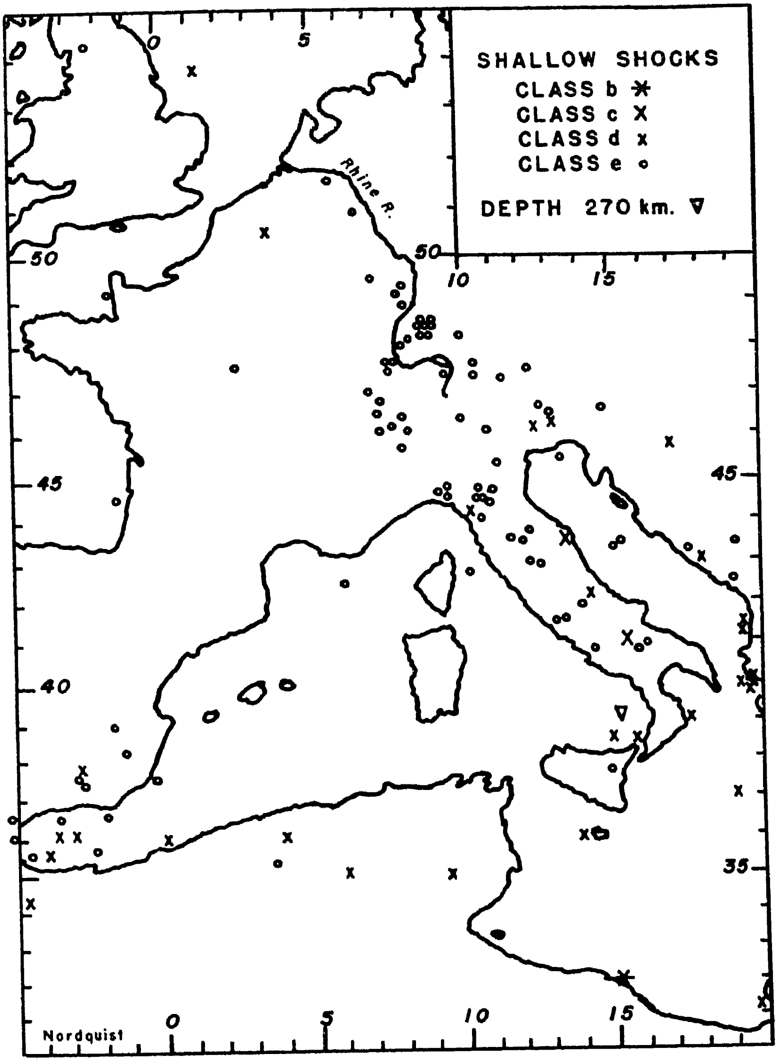

FIGURE 14.—*Map of epicenters, western and central Europe*

For a recent discussion of the Rhine structures considered as rifts *see* Cloos (1939, p. 445–462). The Rhine region is capable of producing an occasional shock comparable with those of Table 20. (*See* Sieberg, 1940.) Such were the strong shock at Basel in 1356, and the South German

earthquake of November 16, 1911. The latter provided much valuable seismological information bearing on the crustal structure of Europe (Gutenberg, 1915). The Belgian earthquake of 1938 (Table 20) perhaps belongs with the following group.

The northern region of Caledonian folding (Stille's *Palaeo-Europa*) shows notable minor seismicity. In view of the complete quiescence of much younger structures, it is highly improbable that these shocks represent any persistence of the Caledonian orogeny to the present time. Stresses of more recent origin have produced fractures in the Caledonian mass, or have rejuvenated old faults of Caledonian age. In Scandinavia these stresses are generally attributed to the uplift of the land after removal of the Pleistocene ice load. (*See* Gutenberg, 1941.)

The history of Norwegian earthquakes was summarized by Kolderup (1913), in a paper which has been followed by a series of annual reports. The available history is comparatively short, Kolderup's earliest shock being dated 1612. Probably none of these shocks were larger than class *d*. Instrumental records are available for the largest (October 23, 1904). This was a shock similar to those of Table 20 in the Skagerrak near $58\frac{1}{2}°$ N. $10\frac{1}{2}°$ E. On March 9, 1866, there was a somewhat smaller shock on the northwest coast near Trondhjem and Kristiansund.

The compilation for Great Britain by Davison (1924) is the most extended critical history available for a region of such low activity. Davison lists the earliest authentic British earthquake as of date 974. His list suggests nearly uniform seismicity in the time covered, as the frequency of listed shocks does not greatly vary until the beginning of scientific investigation in the seventeenth century. The low level of activity is apparent from the fact that from 974 to 1924 Davison lists only 1191 shocks, of all sizes down to the smallest; and over 600 of these are accounted for by swarms of minor shocks at Comrie and Menstrie in Scotland. As Davison points out, the activity in Scotland differs from that in England and Wales; more small shocks are known in Scotland, and the stronger shocks there constitute a large fraction of the total for Great Britain. The Scottish shocks are more plainly associated with known structures than the others; thus many important shocks have occurred along the Great Glen Fault, at Inverness and southwest of it.

The largest shock listed by Davison occurred at Colchester, in the southeast of England, in 1884. The North Sea shock of 1931 (Table 20) was still larger, and thus ranks as the largest shock in the British region for a thousand years. Other shocks have occurred still farther out in the North Sea, such as that of January 9, 1927, near 59° N. 5° E.

The region designated by Stille as *Meso-Europa* is transected by the Rhine belt of activity; otherwise its seismicity is extremely minor. For a discussion of Germany *see* Sieberg (1940). Swarms of small shocks in

Vogtland, Saxony, have been described by Etzold (1919). Small locally damaging shocks have occurred about the coasts of France, particularly near Nantes and in the Channel Islands; similar shocks are known from the coast of Portugal, although some of the destructive shocks affecting that region originated far to the southwest in the Atlantic continuation of the Mediterranean zone.

AUSTRALIA AND OTHER REGIONS

Australia east of the stable mass is a region comparable with the Appalachian belt of North America in structure and seismicity. The known shocks are all small; most of them are on the south and southeast coasts, particularly near Bass Strait. The marginal shocks of the stable mass near the west coast and in South Australia have been previously noted. The small shocks of the interior of Queensland may possibly also be marginal in the same sense. One of these was responsible for the establishment of a station at Brisbane. (*See* Bryan and Whitehouse, 1938.) The seismicity is on a lower level than that usually considered in this study.

The Cape region of South Africa is also one of Palaeozoic folding. Shocks occur in the interior, marginal between the Palaeozoic area and the African stable mass. The shocks of the Mendoza region in Argentina (discussed with the Pacific belt) are similarly placed between the border of the Brazilian shield and the Palaeozoic pre-Cordillera.

MINOR SEISMICITY

Minor earthquakes occur almost anywhere. Practically all existing seismological stations have recorded local earthquakes in their immediate vicinity. However, seismographs with long-period characteristics, such as are suitable for recording distant earthquakes, often fail to write legible records of nearer shocks, even when these are perceptible at or close to the station. Short-period instruments, which are sensitive to small local shocks, have mostly been installed in active areas; comparatively few are in regions of minor seismicity.

This influence of the type of seismographic installation on our knowledge of local seismicity is demonstrated by recent developments in the northeastern United States. This had long been considered as a region of rare seismic disturbance, although a few moderately strong shocks (such as that of 1755) were known. Since the installation of short-period Benioff instruments at several stations in this area an unexpectedly large number of small local earthquakes are regularly recorded. The bulletins of the Northeastern Seismological Association show local disturbances each month. Some of these have been traced to artificial sources such as quarry blasting; but many are undoubted natural earthquakes.

There are few regions where we have both historical and instrumental

data on minor activity. Europe is the only area of low seismicity for which both are available, and even in Europe many of the instruments are ill-suited for the study of minor local shocks.

The somewhat different problem of minor activity in a region of marked

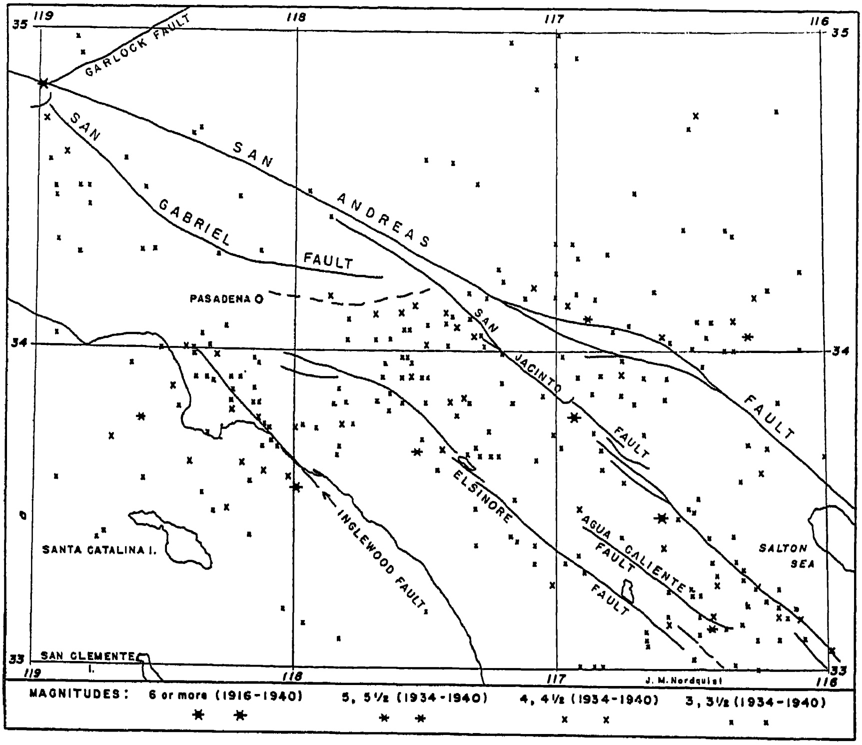

FIGURE 15.—*Map of epicenters and faults, southern California*

seismicity may be studied with the aid of the results in southern California, where a local group of eight stations is in operation, with supplementary data available from temporary installations and stations outside the area.

Figure 15 shows all epicenters for shocks of magnitude 3 or more in the area 33°–35° N., 116°–119° W. during the years 1934–1940 inclusive. Each epicenter is given a symbol indicating the magnitude of the largest shock associated with it in that period. The numerous smaller shocks from identical epicenters are not indicated. In addition, shocks of magnitude 6 and over in recent years have been shown, as follows:

1916, Oct. 23	02^h	34.7° N.	118.9° W.	San Andreas Fault
1918, April 21	22^h	33.7° N.	116.9° W.	San Jacinto Fault
1933, March 11	01^h	33.6° N.	118.0° W.	Inglewood Fault
1937, March 25	16^h	33.5° N.	116.6° W.	San Jacinto Fault

The principal known faults are indicated in the figure; the "foothill fault zone," consisting of a series of disconnected traces along the front of the San Gabriel range, is shown as a dashed line. The general lack of clear association between minor shocks and important faults should be noted. Most of the many small shocks are located close to one or another of the numerous minor faults which are common throughout the region. Only the larger shocks show definite association with the larger fractures. It should be added that the only major earthquake known to have occurred in this area, that of January 9, 1857, originated on the San Andreas Fault. There was probably displacement along all that part of the fault shown on the western half of our map, extending northwest far beyond its limits. In recent years most of this part of the fault has been almost completely quiescent (note the absence of epicenters for small shocks); the same applies to most of that segment of the same fault zone along which displacement took place in the major earthquake of 1906, farther north.

In a later section it will be shown that the larger earthquakes represent a dominant fraction of the seismic energy released. Thus it follows that most of this energy is released along the major structures.

GEOGRAPHICAL SUMMARY

The results of the study are presented in summary form in Figure 16. Instead of using individual epicenters, this map represents the active zones as continuous, though care has been taken to break them where present evidence does not seem to warrant drawing them through. The zones are shown as widened where activity is intense. Shallow, intermediate, and deep earthquake zones are distinguished by different shading.

Deep shocks, in the restricted sense, show a distribution which is difficult to interpret. Like the shallow shocks, they occur chiefly in belts or zones, although it is not known whether the limited active areas in South America (Fig. 4) are parts of a single belt. These belts are rather plainly associated with the circum-Pacific structural and seismic belt, which must then be taken to include the Sunda arc in the East Indies. Belts of deep shocks often run roughly parallel to surface structures, and generally on the side away from the Pacific basin. In some regions, as near the Sunda arc and the Marianne Islands, this paralleling is at shorter distance than in others, like Manchuria. The transverse belt across the Japan Sea diverges completely from the apparently associated belt of surface structures.

In the Pacific region intermediate shocks occur in belts which are usually parallel to belts of shallow shocks, and almost always run directly along orogenic lines of Cretaceous or Tertiary age. These lines are generally also those of active or recently extinct volcanism; but in many parts of the world, notably in the Atlantic and in Hawaii, volcanoes are not accompanied by intermediate shocks.

Outside the circum-Pacific belt intermediate shocks are known only from a few localities in the Alpide part of the trans-Asiatic zone. Among these are the very active sources in Rumania and in the Hindu Kush; several others are related to the folds surrounding the Indian stable mass.

There are some well-known seismic zones characterized by a large majority of intermediate shocks, with a few shallow shocks, and earthquakes of large magnitude in both classes. Among these are the west coast of South America, the Marianne Islands line, and the vicinity of the New Hebrides.

Especially in the Pacific region there are numerous cases where the belts of shallow, intermediate, and deep shocks have a particular relation to the surface structures. Shallow shocks occur between the oceanic troughs or foredeeps and the nearest land or island chain; intermediate shocks generally under the island chains (the orogenic lines of late date, noted above); and very deep shocks still farther removed from the ocean troughs. In northern Japan and the Marianne Islands line the oceanic front of this structure is that of the deeps bordering the main Pacific basin; in South America and the Philippines the front is on external parts of the Pacific Ocean, probably continental in structure; in the Sunda arc the front is on the Indian Ocean. Finally, in the region of the New Hebrides and Solomon Islands the front, with its foredeeps, is on the southwestern side, away from the Pacific basin, and the whole order of structures is reversed from that prevailing farther east and west.

In several regions, such as Japan and South America, there are two separable groups of intermediate shocks; one at depths near 100 km., the other at 200 to 300 km.

Shallow shocks chiefly occur on the circum-Pacific belt with its various branches, the trans-Asiatic zone, and the Arctic-Atlantic and Indian Ocean belts. The latter two, as well as the Easter Island branch of the Pacific belt, follow oceanic ridges which are in reality submarine mountain ranges, corresponding to the manner in which other seismic belts follow known mountain systems and island chains.

Some other important shocks have been described as marginal to the continental stable nuclei. In general these shocks do not fall on the edges of the continental shelves, save for a few cases where there is reason to suspect that the edge of the shelf coincides with that of the stable shield. Apart from this, the limits of the shelves are nonseismic; if they are determined by structures, those structures are now inactive.

The seismic zones divide up the entire surface of the globe into blocks, the interiors of which are relatively nonseismic. One of these blocks is the Pacific basin; the others, at least the larger ones, are continental in character. In the central region of each continental block is the stable shield or continental nucleus, with active interior fractures and marginal seismicity.

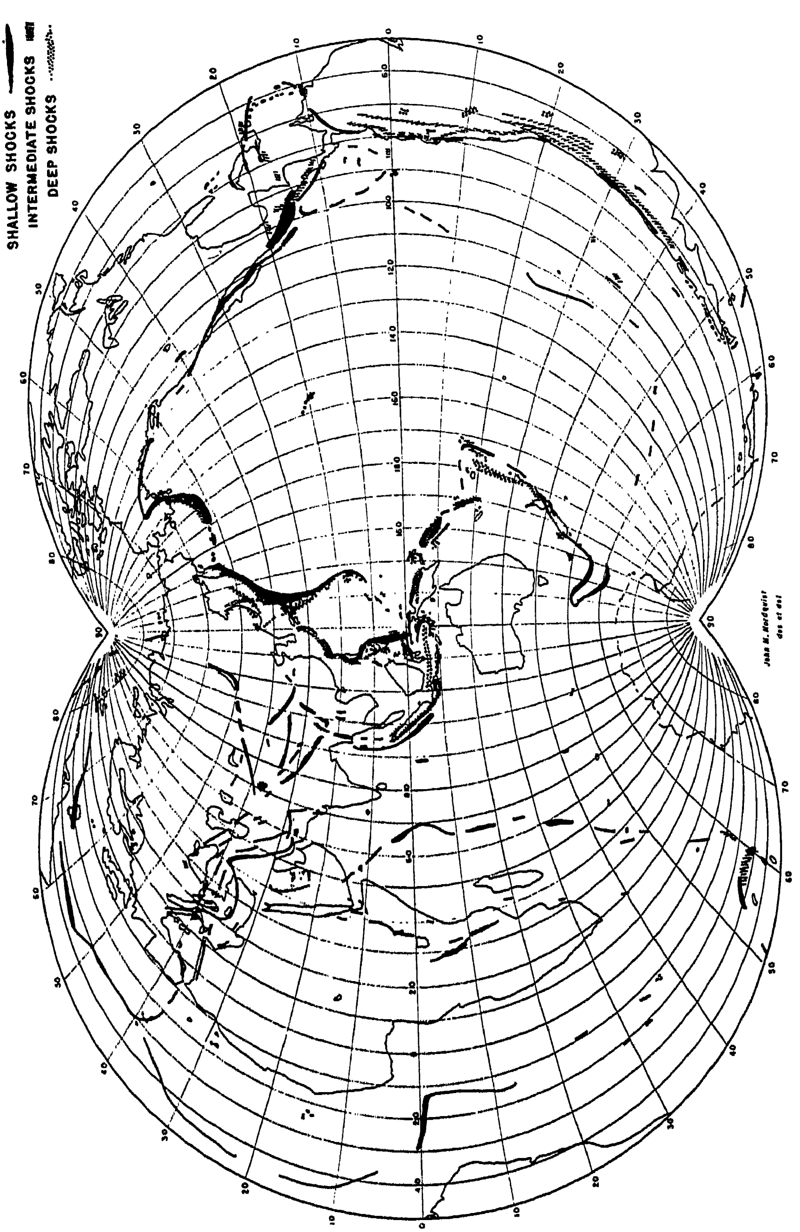

FIGURE 16.—*World map showing seismic belts*

Between this stable shield and the active zones bounding the block is a wide zone which is not quite as inactive as the stable shield itself. That part of this substable zone adjacent to the stable shield often contains an old mountain system, such as the Appalachian system or the mountains of eastern Australia; in such a mountain system the seismicity is often slightly higher than in surrounding areas.

The exact boundaries of the blocks are not always clearly defined. Thus, the North American block lies between the Pacific and Arctic-Atlantic belts. Should it include the substable region of northeastern Asia as well as northern Alaska? There is nothing to separate the North and South American blocks on the Atlantic side. The African block is not well defined on the northeast, where its relation to the Arabian mass is uncertain, and may be compared with that of North America to Greenland. The mutual boundaries of India, Australia, and Antarctica fall in the Indian Ocean where shocks are few and other data incomplete.

There are isolated areas of Pacific structure. The two most definite of these are the Caribbean and the region surrounded by the Southern Antilles between South America and the Antarctic; the former is definitely closed, while the latter may not be. The status of the similar Macquarie Island loop is uncertain. It is not known how much of the Antarctic Pacific is continental in character, but the region may contain several areas of Pacific type. Evidence from amplitudes of reflected seismic waves suggests an area of Pacific type in the Arctic basin off the northwestern American coast.

FREQUENCY AND ENERGY OF EARTHQUAKES

Very little can be stated about the frequency of occurrence of deep-focus earthquakes. Even the larger deep shocks are catalogued with reasonable fullness only since about 1931. Small deep-focus shocks are hard to identify, and the magnitude of the smallest such shock which can be listed in a given region depends largely on the number and equipment of the local stations. Thus, the numerous local stations in Japan, together with the close attention of Japanese seismologists to the problem, makes the listing for the vicinity of Honshu, at least, more complete than anywhere else in the world; while in South America, the possibility of studying simultaneously the records written at Huancayo and at Pasadena has led to listing many shocks, especially at intermediate depths, which otherwise would have been overlooked. On the other hand, it is well established that deep shocks have been lacking in California, at least in recent years.

Table 21 shows the total number of known deep-focus shocks; the depth ranges are within 25 km. of the depths given at the head of each column. Numbers are listed separately for the chief active areas. Shocks less

than 80 km. deep have been omitted; in many regions it is nearly impossible to separate them from shallow shocks, and their number is undoubtedly greater than that indicated by the small representation in our lists.

TABLE 21.—*Number of shocks listed at various depths*

Region	Depth in km. (Range ±25 km.)												
	100	150	200	250	300	350	400	450	500	550	600	650	700
Mexico, Central America........	20	4	2		1								
South America..................	46	22	18	7	2					1	5	11	
New Zealand, Tonga, Samoa.....	11	3	3	1	2	1	4		6	9	10	5	1
New Hebrides to New Guinea....	22	16	9	1	2	3	3	1					
Sunda Islands..................	21	12	9	1		1	3		1		10	1	5
Celebes to Mindanao............	3	6	10	2	4		1		2	1	3	1	1
Luzon to Kiushiu...............	10	7	4	3									
Japanese Islands...............	33	26	12	5	12	27	25	12	14	14	6	1	
Hindu Kush.....................	1		14	25									
Others.........................	11	13	1	1									
Total..........................	178	109	82	46	23	32	36	13	23	25	34	19	7

The number of shocks falls off rapidly with increasing depth, down to the lower limit of intermediate shocks at 300 km.; below this the general distribution for the whole earth is fairly uniform with depth until the greatest depths are approached. This is not true of the individual regions, since nearly every limited area has two or more characteristic depths near which shocks are most frequent.

The range in magnitude for deep shocks appears to be about the same as for shallow shocks, but no safe criterion has been applied to assign magnitude to a deep shock. Even from the greatest focal depths known, some shocks are recorded with body waves as large as those of the largest shallow shocks.

The following discussion refers exclusively to shallow shocks so that conclusions with reference to the general seismicity of the earth are subject to modification whenever it becomes possible to take account of deep shocks systematically.

For the larger magnitudes, data are given in Table 22. From $8\frac{1}{2}$ to 8 the shocks are all from Table 5. There are 36 in 37 years. For $7\frac{3}{4}$ there are 18 shocks in Table 5; 2 shocks given in Table 4 as 7.7 have been added to this total. Combined averages are 1.0 shocks per year of magnitude 8 or over, and 8.3 shocks per year of magnitude 7 to 7.9. Classification of shocks in the International Summary for 1931–1933 gives about 284 earthquakes of magnitude 6 to 6.9 or about 95 per year.

The shocks of lowest magnitude in each table are probably slightly too few in number, as doubtful cases have generally been omitted. At these lowest levels in the respective tables it is probable that the geographical coverage is incomplete, so that shocks in remote regions have escaped inclusion. This is certainly true for the shocks of class *d*.

TABLE 22.—*Frequency of large shallow shocks*

Magnitude	No. of shocks		No. per year
8½	4	37 years	0.1
8¼	8		0.2
8	24		0.6
7¾	20		0.5
7.6–7.4	12	8 years	1.5
7.3; 7.2	24		3.0
7.1; 7.0	26		3.3

To sum up, there are roughly: one shock per year of magnitude 8 and over, 10 shocks of magnitude 7 to 7.9, and 100 shocks of magnitude 6 to 6.9. Over this range there is approximately a tenfold increase in frequency for every decrease in magnitude by one unit.

No reliable statistics for shocks of magnitude less than 6 can be set up for the world as a whole. Such shocks must be studied in limited regions, on the assumption that in general they bear a constant proportion to the larger shocks of the corresponding areas.

At present Southern California is the only area for which shocks of the smaller magnitudes are recorded, located, and catalogued with sufficient regularity for the purpose. Data used in the following paragraphs have been compiled by Mr. R. E. Rogers, who is also responsible for a majority of the epicentral determinations, and for routine assignments of magnitude to the nearest half unit on the Pasadena scale.

For the years 1934 to 1939 inclusive, and for an area selected for its favorable situation with respect to the recording stations, including most of Southern California and a small part of adjacent Mexico, the numbers are:

Magnitude	No. of shocks	Sum
6	2	4
5½	2	
5	14	65
4½	51	
4	150	486
3½	336	
3	677	

Shocks of magnitude less than 3 are omitted, as they certainly are not uniformly catalogued over the area. Those of magnitude 3 are probably not completely covered, particularly in the remoter corners of the area. Noting this, the rule of tenfold increase in the number of shocks for one unit decrease in magnitude still holds approximately.

For smaller shocks the data are fairly complete for the same years, 1934–1939, in the area between the limits $33\frac{1}{2}°–34\frac{1}{2}°$ N., 117°–118° W. This lies just east of Pasadena, and is well covered by the three first-class stations at Pasadena, Mt. Wilson, and Riverside (Fig. 15). The following list probably includes all shocks in this small area down to magnitude $2\frac{1}{2}$. The number for magnitude 2 is probably somewhat too small, but not by any large factor, as shocks of that size write conspicuous records on the sensitive short-period instruments at the stations named. Some of these may be due to blasting operations (even major blasts seldom exceed magnitude 2 seismometrically).

Magnitude	No. of shocks	Sums
$5\frac{1}{2}$	1	1
5	0	
$4\frac{1}{2}$	8	18
4	10	
$3\frac{1}{2}$	23	109
3	86	
$2\frac{1}{2}$	122	298
2	176	

This supports the rule of tenfold increase down to magnitude 3; but the smaller shocks are evidently not so numerous as might be expected on that basis. This is of course to be anticipated, as the number of earthquakes cannot go on increasing uniformly with decreasing magnitude, but must have a maximum of frequency at some level.

Assuming that the Californian shocks are representative of general conditions, and attaching the results from California to those found directly for the whole world in the higher magnitude levels, the conclusions follow:

	Magnitude	Annual number
Great earthquakes	8 or more	1
Major earthquakes	7–7.9	10
Destructive shocks	6–6.9	100
Damaging shocks	5–5.9	1000
Minor strong shocks	4–4.9	10000
Generally felt	3–3.9	100000

The total number of shocks potentially strong enough to be perceptible to persons in a settled area (magnitudes 2 and over) must be of the order of several hundred thousand per year. Including aftershocks and swarms of small shocks, the total may be well over a million.

Extrapolation to the high side would suggest one shock of magnitude 9–9.9 about every 10 years. Certainly since 1900 no shock over magnitude $8\frac{1}{2}$ has taken place. None of the greater shocks for which we have reliable historical descriptions appear to have been of much higher magnitude, although a shock of magnitude $9\frac{1}{2}$ would release energy about 100 times that of the largest known shock, and ought to occupy an exceptional place in the historical record. The great Indian earthquake of 1897 apparently showed no effects exceeding those of the Kansu earthquake of 1920; and the seismograms of the Alaskan shock of 1899 suggest a magnitude between $8\frac{1}{4}$ and $8\frac{1}{2}$. A more serious question relates to the magnitude of the Lisbon earthquake of 1755, since the phenomena of seiches indicate that the surface waves were very large over the whole of western Europe. Even this shock could hardly have exceeded magnitude 9.

Presumably the frequency of earthquakes decreases rapidly as the magnitude approaches an upper limit. This limit must be set by the strength of crustal materials, so that it is impossible for stresses to accumulate beyond a certain critical value. From isostatic data, Tsuboi (1940) calculates the maximum energy of an earthquake as 5.6×10^{24} ergs. This agrees within the limits of error with the energy of the largest earthquakes.

At the other end of the scale, there is probably a lower limit for the magnitude of ordinary earthquakes, representing the stress necessary to open a fracture in a weak zone. Just after a large shock, when the zone has already been disturbed and fractured, small stresses more easily produce movement; this partly explains the large number of small aftershocks usually following a large earthquake.

From the figures on frequency given above it is clear that the release of seismic energy occurs chiefly in the shocks of larger magnitude. Thus, although there may be 10 times as many shocks of magnitude 7 as of magnitude 8, each of them releases only 1 per cent of the energy of that released by one of the larger shocks, and the total energy release in magnitude 7 is still only one tenth that in magnitude 8. The relation continues down the scale, as far as the rule of tenfold numerical increase holds. This phenomenon was noted for the lower magnitudes in Southern California in the first paper on magnitudes by Richter (1935). It was found that in any limited district the shocks of largest magnitude occurring during any interval of observation liberate nearly all of the seismic energy for that interval. This result, as shown above, extends to the whole world and to the largest shocks.

Mechanically, it must be concluded that the larger stresses accumulate without reference to the release of energy in minor shocks or along minor structures. In general, it is not true that minor shocks function as a "safety valve" to delay the occurrence of a great earthquake. Rather,

minor shocks on minor structures are symptoms of a regional strain, only a small part of which is being transferred away from the major structures along which it will eventually find release in a major earthquake.

The total energy released by a shock of magnitude $8\frac{1}{2}$ has been estimated at 10^{25} ergs (Gutenberg and Richter, 1936). Using this and the corresponding figures for lower magnitudes, Table 22 shows a release in energy, in shocks of magnitude 8 and over, of 9.0×10^{25} ergs in 37 years, or 2.4×10^{24} ergs per year and 0.4×10^{24} ergs per year for shocks from magnitude 7 to 7.9. If we add one tenth of this for magnitude 6 to 6.9, and so on for lower magnitudes, the energy released by all shocks is close to 3×10^{24} ergs per year, or 10^{17} ergs per second. This means performance of work at an average rate of 10 million kilowatts. Nearly one third of this energy release is represented by the four largest shocks (magnitude $8\frac{1}{2}$) in Table 5 and over 80 per cent by the shocks of magnitude 8 and over.

Of 53 shocks in Table 5, one is in California and another in Nevada; of 68 in Table 4, one is in California. This would suggest assigning to California about 1 to 2 per cent of the seismicity of the world. If that of the southern California area chosen for statistical purposes were taken as one fourth of 1 per cent, there would result about 1000 shocks of magnitude 5 and $5\frac{1}{2}$ annually for the world, as given above.

Roughly 80 per cent of the seismic energy of the world is released in the circum-Pacific belt and its branches, over 15 per cent in the trans-Asiatic zone, and less than 5 per cent in the rest of the world.

This energy is not released at a uniform rate, nor regularly distributed over the seismic regions. There are years, and shorter intervals, when activity is abnormally high, and others when it is unusually low. Further, for a period of weeks, significant activity may be concentrated in a limited region. These effects apparently are within the limits of normal statistical fluctuation but may exceed them in certain regions. (*See* Wanner, 1937.) These highly irregular variations bear no evident relation to the minor periodicities which have sometimes been claimed. These periodicities, superposed on the large general fluctuation, are somewhat controversial; the reader should compare the findings of Tams (1931, p. 419–433), Conrad (1932), and Davison (1938).

Few definite changes in seismicity have occurred during historical time. Chronologically long histories for such active regions as Japan, China, the Near East, and Italy indicate activity of about the same character as in very recent years, with shocks of the same range of magnitudes occurring in the same areas, apart from a few individually exceptional events. For less active regions, the best available history is that of Great Britain, extending over about a thousand years with no sign of secular change.

Otherwise comparatively quiet regions may have short periods of un-

usually high seismicity. The following is quoted from Kunitomi (1937, preceding p. 1):

"Now-a-days, in Tyôsen, slight attention is given to the study of earthquake owing to a minority of local shocks. Nevertheless, about 300 years ago, at an active period, frequent strong shocks were experienced all over the peninsula and inflicted severe damage to the buildings and human beings. Therefore, the seismological observation must not be neglected even in the present time of less activity."

A recent case of this sort is that of the long series of strong shocks in the Indian Ocean, near 34° S. 57° E., from 1925 to 1933. In a settled area such a series of shocks would have brought about a series of disasters. There may have been such a time of increased seismicity on the African Rifts about 1910–1913. An unusual number of very destructive shocks is known from Palestine and Syria during the eleventh and twelfth centuries.

Individual shocks, or brief groups of large shocks, frequently have this exceptional character. Examples are the Mississippi Valley shocks of 1811–1812, the Charleston earthquake of 1886, the Baffin Bay shock of 1933, the west Cuban earthquake of 1880, and the destructive shock at Basel in 1356.

Seismicity must have changed greatly in the course of geologic time. Stresses producing shocks in northern Europe have been attributed to unloading of the Pleistocene ice burden; this may apply to some of the Canadian shocks. Though present seismicity affords almost no clue to the location of the geologically older structures, yet the formation of these structures must have been accompanied by many earthquakes. Present evidence of broad regional association of earthquakes and volcanoes may be applied to stratigraphical and structural evidence of past volcanism in many parts of the world which are now relatively stable. Contemporary shocks at intermediate depths follow volcanic lines, which in their turn follow Tertiary orogenic trends.

How far the present major active belts can be traced back into geological history is an important question, to which only tentative answers are possible. The circum-Pacific belt, in one form or another, has certainly had a long history, corresponding to the geological antiquity of the Pacific basin; its several sections and branches have undoubtedly undergone many changes and much deformation. The history of the trans-Asiatic zone must be connected with that of the inland sea Tethys. The Atlantic and Indian Ocean belts mark the contacts between important sections of the crust, which have certainly existed as units during most of the Tertiary while their remoter history is more doubtful.

EARTHQUAKES AND OTHER PHENOMENA

The association of volcanic and seismic regions is rather general and loose. Both earthquakes and volcanoes are connected with the weaker

crustal zones, and consequently show a similar distribution over the world when studied on a small-scale map. Both are most frequent in the circum-Pacific belt of structures and its branches. Proportionately fewer volcanic vents than earthquakes are known in the trans-Asiatic zone; while volcanoes, and islands of volcanic rock, are frequent in the Atlantic and Indian Ocean in association with moderate seismic activity.

Volcanic vents are usually at distances measured in hundreds of kilometers from the principal tectonically active faults and structures. This applies to shallow earthquakes only, since intermediate shocks frequently occur directly under the structures marked by volcanic vents.

Probably no causal connection exists between intermediate shocks and present volcanic activity, since both are very likely due to the same remote orogenic processes.

Large gravity anomalies have been much studied with reference to earthquake epicenters, since such anomalies suggest an abnormal condition of the crust likely to be accompanied by unusual stresses. Narrow belts of large negative gravity anomalies are known to occur off Japan, in the East Indies, and in the West Indies. These anomalies are generally found associated with oceanic troughs or foredeeps, however, the greatest negative anomaly is generally not over the trough, but adjacent to it. This adjacent belt is frequently marked by epicenters of shallow earthquakes.

Troughs, rises, belts of gravity anomalies, volcanic chains, and seismic belts of different classes tend to occur together in a definite order of association, which is best explained with reference to a particular example (Fig. 17). The hypocenters of shallow and deep earthquakes near the section AB are projected onto the plane of the section. Gravity data are taken from Matuyama (1936). (*See also* Kumagai, 1940.)

In this region earthquakes, gravity anomalies, volcanic vents, and structures are aligned along relatively narrow belts with a northeast-southwest trend. The section crosses these belts nearly perpendicularly. Near its southeast end the deep Pacific basin descends into the deeper Japan Trench. Shallow shocks occur chiefly under the steep continental slope west of this trough. Along this slope is the belt of greatest negative gravity anomalies, the greatest seismicity practically coinciding with the center of the belt. On land the gravity anomalies become positive, and are accompanied by volcanism and shocks at intermediate depth down to 250 km. The deeper of these probably form part of a separate belt of epicenters. The second volcanic belt marked in the figure probably coincides only accidentally with the epicenters of certain deep shocks, since it has a nearly north-south trend, while the line of deep shocks crosses it in a northeast-southwest direction (Fig. 8). The still deeper shocks shown under the Asiatic mainland are part of another belt.

The foci of deep and intermediate shocks appear to fall on a single smooth

surface dipping at about 30 degrees under the continent. However, in no region where deep shocks can be investigated, is there conclusive evidence of such an active surface; rather, the shocks occur in belts traversing the hypothetical surface, and leaving large parts of it blank. This may be

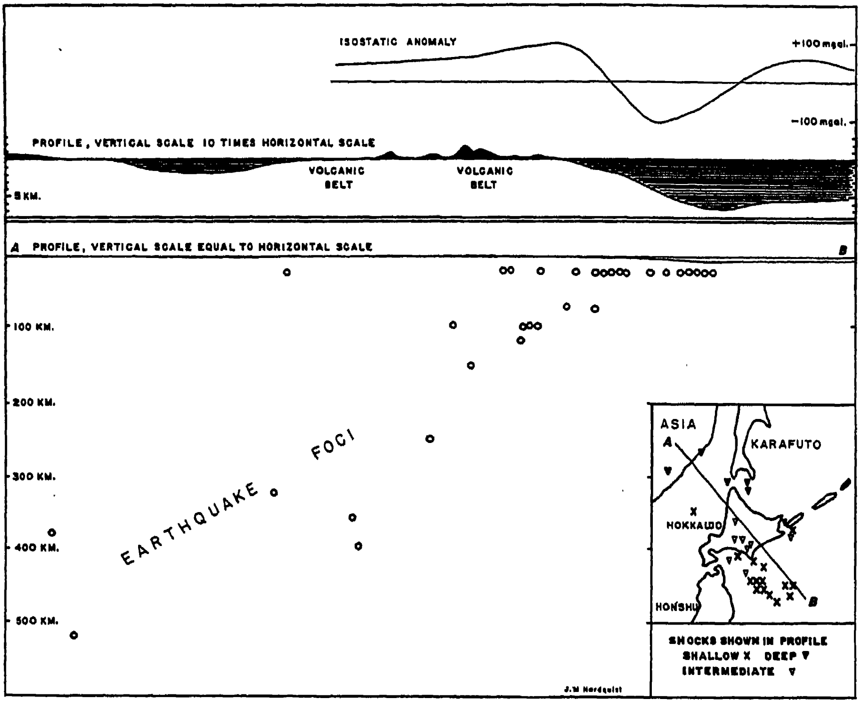

FIGURE 17.—*Profile, northern Japanese region*
Showing earthquakes hypocenters, relief, and isostatic gravity anomalies

due to the incompleteness of our information, or the active belts may be intersections of the supposed surface with other structures. Such an inclined surface need not be a continuous fracture zone, but may simply be a locus of maximum stress.

Like most "typical examples," Figure 17 is exceptional in that all the features which it is desired to illustrate are clearly represented. The choice of such sections is especially limited by the lack of gravity data in many important regions. A more or less continuous belt of negative gravity anomalies runs east of the Marianne Islands and then northeastward in the vicinity of the deep troughs off Honshu (Matuyama, 1936). The known belt begins at about 28° N. 143° E. and trends slightly west of north, following the west slope of a trough, accompanied by shallow shocks (Fig. 8). West of this, along the line of small islands, is the much more

active belt of intermediate shocks, accompanied by positive gravity anomalies. Near 35° N. the gravity anomalies are less marked; but they become strongly negative again to the north, where there is very high seismicity.

In a (unpublished) discussion at the 6th Pacific Science Congress in 1939, Professor Matuyama stated that "strong negative anomalies follow the eastern coast of Honsyu at some distance off the coast and turn in the direction of the Marianne Islands in the neighborhood of the Fossa Magna. In the central and southern parts of Honsyu positive gravity anomalies prevail. A line of minimum gravity anomalies which, however, in most of the region still are positive, follows the central part of southern Honsyu and then turns southward. This minimum coincides with the belt of shallow earthquakes in this region."

All these phenomena are well exemplified in the region of Sumatra and Java. The gravity data are those of Vening Meinesz (1940). The structures and attendant phenomena are distributed along a series of curving bands parallel to the trend of the Sunda arc (Fig. 9). Beginning at the south and west, the floor of the Indian Ocean rises gradually to shallow depths, emerging at Christmas Island. North of this belt of shallow sea there is an extremely steep descent into the Java Trough, a typical foredeep. Off Sumatra this descent is not so steep, and the depth reached is shallower. Next inland is a line of small islands, separated by shallow straits, off the Sumatran coast. This line continues as a ridge, which does not emerge, off the coast of Java north of the Java Trough. The belt of strong negative gravity anomalies, discovered by Meinesz, practically coincides with this ridge. Between Java and the Java Trough these anomalies are large, but there is little accompanying seismicity; while in the continuation of the same belt, along the islands west of Sumatra, the negative gravity anomalies are less marked, and the seismic activity is intense, consisting exclusively of shallow shocks. Inshore from this belt slightly greater depths again occur before the coasts of Sumatra and Java are reached. This coastal belt is a region of positive gravity anomalies and earthquakes at intermediate depth. The deepest of these shocks occur under the volcanic belt of the two large islands. Finally, in the seas north of Java there is an east-west belt of shocks at very great depth.

Elsewhere in the East Indies the structural conditions are more complicated, which renders discussion of the meaning of gravity anomalies more uncertain. The belt of strong negative gravity anomalies runs round the Banda Sea from Timor to Ceram, and includes the few well-located shallow shocks, while intermediate shocks are clearly interior to the arc. Such structures as the Weber Deep interior to the arc, and the line of islands through Flores and Weter, complicate the pattern to be interpreted. The gravity anomalies and seismicity of Celebes are still

harder to bring under any generalization. Between Celebes and Halmaheira a very strong belt of negative gravity anomalies follows a small submarine ridge northward to the Talaud Islands; there is strong seismicity at shallow depth along the same line. A line of intermediate shocks crosses here from west to east, and there is other activity near by.

A belt of strong negative gravity anomalies also exists in the West Indies, where it is associated with deep troughs, volcanism, and seismicity. For the gravity data and discussion *see* Hess (1938) and Daly (1940, p. 285). Shocks in this region are relatively few, and often not well located. Only in the vicinity of the lesser Antilles do the phenomena simulate those in the East Indies and off Japan. Strong negative gravity anomalies occur to the east, near the Barbados Ridge; while the islands themselves (excluding Barbados) are to the west, and are associated with volcanism, positive gravity anomalies, and at least one intermediate shock.

The few gravity observations available in the Tonga region (*see* Heiskanen, 1936; Daly, 1940, p. 255) fit in well with the existence of an oceanic trough, volcanism, and shocks at all depths, to complete a pattern similar to that of the Sunda arc. The only other region in which available gravity data suggest something of the same sort is in northern India. (*See* Daly, 1940, p. 224–247.) Here there is a narrow belt in which gravity anomalies are strongly negative, although they can be removed in large part by a special choice of isostatic reduction. This is interesting in view of the common comparison of the Ganges depression to foredeeps like the Java Trough. The location of the gravity anomalies, and of the belt of shallow earthquake epicenters, is quite analogous to that found elsewhere. However, the few intermediate earthquakes known here are a poor counterpart for those of the Sunda arc (the active Hindu Kush source is much farther west); no deep shocks occur; and there is no comparable volcanic activity.

Observations in the Atlantic Ocean have not disclosed any gravity disturbances comparable with those noted above. The mid-Atlantic Ridge is not marked by any outstanding gravity anomalies, so far as present information goes. (*See* Meinesz 1939.) Negative anomalies are known from the region of the African Rifts (*see* Heiskanen, 1936), and very large positive anomalies recently have been found on Cyprus (Mace and Bullard, 1939).

The unilateral grouping of oceanic troughs or foredeeps, gravity anomaly belts, shallow and deep earthquakes, and volcanism is most frequently found on the Pacific margin, as in the type case of Japan. The outermost structure usually is the deep trough, with earthquakes and other phenomena occurring in order, successively farther from the Pacific basin. In the case of the Sunda arc, the Indian Ocean plays the part which is elsewhere taken by the Pacific. In the West Indies and in the Southern Antilles, the Atlantic occupies this position.

The polarity of the whole series of structures in any given region can usually be inferred from the relative position of oceanic troughs and land structures; where the structural lines are curved, the troughs are usually on the convex side. In the New Hebrides and Solomon Islands, the polarity is apparently the reverse of that in most parts of the Pacific margin. Here the troughs are on the southwestern, or continental side, the shallow shocks are between these and the island chains, while intermediate shocks are under the islands or beyond them toward the open Pacific, with a few deep shocks still farther out.

The whole complex of related structures and phenomena is plainly produced by stresses which are usually associated with the boundary of the Pacific, but which may locally assume either polarity with reference to it. This polarity, or one-sidedness, excludes symmetrically bilateral physical models. The not fundamentally dissimilar one-sided models of Kuenen (1936) and of Griggs (1939) probably can be modified to fit the facts.

Their frequent association with earthquakes is only one type of evidence indicating that oceanic troughs, or foredeeps, are due to processes still active and continuing, as is required by the mechanical models. This is important since it is sometimes suggested that persistence of these structures, together with large negative gravity anomalies, implies great strength of the crust and the underlying material, or a relatively high viscosity (in excess of 10^{23}). Otherwise, it is argued, the troughs in question would have only a very short term of existence on the geological time-scale. On this basis the crust should adjust itself only very slowly to inequalities of stress; this conflicts with the usual interpretation of the post-glacial uplift in Fennoscandia and Canada, which calls for a relatively rapid return toward isostatic conditions with removal of the glacial burden. Apparently it would then be necessary to seek some other explanation of this uplift, and calculations of the viscosity of the crust based on the rate of uplift would be invalidated. This type of argument ignores the possibility that stresses, such as may be associated with subcrustal convection, are regularly at work maintaining the crust in its deformed state. In such a model it must be noted that deep-focus earthquakes should be expected to occur not at the level of maximum flow, but at that of maximum stress associated with the flow.

Many authors have correlated deep and shallow earthquakes with oceanic troughs and deeps. This is a general correlation like that with volcanic activity; it applies to small-scale maps, but requires modification in detail. Epicenters usually do not fall in the deep troughs themselves, but on their marginal slopes or along the crests of adjacent submarine ridges. Frequently, as occurs south of Sumatra and Java, the ridge adjacent to the deep is not seismically active, but becomes active in another part of its course where the adjacent depths are less marked.

However, most of the greater deeps are in regions where seismicity is at least moderately high. This of course applies to the true structural troughs, and not to the irregular areas of great depth which occur in the oceanic basins, particularly in the Pacific. On the other hand, earthquakes occur in many oceanic regions, as in the Atlantic and Indian oceans, where there are no associated deeps; the seismic belts then follow the ridges.

Structures of somewhat different character, usually associated with seismicity, are the great elongated depressions in the interiors of some of the continents. Examples are the great African lakes, Nyasa and Tanganyika, and in Asia, Lake Baikal, the Turfan basin, and the Jordan Valley. The mechanism which has created and maintained rift depressions of this kind probably differs from that assumed for the oceanic troughs.

MECHANISM

In discussing dynamical implications of the present seismicity of the world, it must not be forgotten that contemporary earthquakes indicate only the fractures, stresses, and displacements now in action. These may well differ, and in some cases they certainly do differ markedly, from those associated with the formation of even late Pleistocene structures. A few tens of thousands of years is ample time for extensive and significant changes in the local distribution of stress. Thus, the fact that the present seismicity of Europe is not mechanically connected with the Alpine folding has been emphasized by Sieberg (1932a), who attributes contemporary shocks to fractures produced in the rigid Alpine mass after the conclusion of folding. However, his ingenious localization of these fractures on the basis of the very limited earthquake data has not found general acceptance.

Except for comparatively superficial volcanic shocks, earthquakes represent a process of fracturing involving shear. Present evidence indicates that this is as true of deep shocks as of shallow shocks. Consequently, in dynamic interpretations of earthquakes the mantle of the earth must be considered capable of first supporting large shearing stresses, and then fracturing as these become still larger; this must be true, at least locally, down to the depths near 700 km., the lower limit of deep-focus shocks as now known. This is not inconsistent with the plastic flow required to maintain isostasy, as all evidence indicates that the material of the mantle flows slowly under long-continued and constant stress, with a more or less incidental accompaniment of sudden fracturing. (*See* Gutenberg and Richter, 1939b.)

Division of the earth's surface into comparatively rigid blocks has an important bearing on tectonic hypotheses. It calls especially for interpretation in connection with any of the forms of the theory of continental drift. Undoubtedly these blocks have not always had exactly their present size and shape, and they may have greatly changed their relative po-

sitions. At present we know that in certain regions, as in California, large-scale horizontal displacements continue in the same sense over the whole region, and apparently have operated in the same or a similar way through most of Recent time. Comparison with the direction of similar horizontal displacements on the opposite side of the Pacific, as in the Philippines (Willis, 1939b) and Japan (Tsuboi, 1939), indicates that the continental masses on both sides are being pushed southward relative to the Pacific basin. Many more observations are needed before this can be accepted as an established fact of extended application. There is both seismological and geological evidence in other parts of the world that displacement is occurring continuously in the same direction.

A result not anticipated by the writers is the frequent close coincidence of the active zones, which are found to separate the stable blocks, with the "orogens" of Kober (1933). As he points out, these zones are chiefly mountainous in character; the ridges in the various oceans are submarine mountain chains. The agreement with Kober's zones is not necessarily a confirmation of his interpretation of these contemporary structures in terms of geological history, or of his ideas about the processes now taking place. The agreement chiefly applies only to the larger lines, and frequently is very divergent in the smaller details. Moreover, Kober does not discriminate the Pacific stable area from the structurally different continental blocks; and he draws "orogens" subdividing the Pacific area, which are unconfirmed by this study and frequently conflict with its conclusions.

Problems of interpretation are especially acute with reference to the existence and seismicity of the Mid-Atlantic Ridge. Its parallelism with the continental coasts is so close that it practically demonstrates a mechanical connection with them. However, it is still possible to consider the Ridge either as a remnant left over from a former connection between America and the Old World, or as a young structure originating at the contact between rigid blocks. (For a summary with references, *see* Du Toit, 1937, Chapter X.) It can hardly be a young structure in the sense in which the very active zones of the East Indies and other similar regions are young, for it lacks many of the associated phenomena found in such regions, which have been taken as evidence for the contemporary occurrence of subcrustal flow. Thus there are no parallel deep troughs, and no belts of negative gravity anomalies; the gravity anomalies over the Mid-Atlantic Ridge are slightly positive (Meinesz, 1939). Intermediate and deep shocks are absent, which indicates that there are no large stresses at great depth. Present seismicity and volcanism do not necessarily imply that the processes which created the Ridge are now in action. The Ridge may represent an orogeny of Tertiary age, in which the folding has at least temporarily ceased, and the now practically rigid structures are being

broken up by diastrophic processes, along faults which are either of recent origin or recently rejuvenated. For a discussion from the geological point of view *see* Bucher (1940).

The foregoing discussion is necessarily speculative, and is intended merely as a guide in using the seismological data. In the major part of the paper, which concludes with the Geographical Summary, care has been taken to present facts of observation, with only the minimum of hypothesis necessary to organize them into an intelligible form. The sections following thereafter necessarily include gradually increasing proportions of hypothetical material. With the suggestions just brought forward it is felt that a foundation for geological and geophysical interpretation has been provided.

GENERAL SUMMARY

The relative seismicity of all parts of the earth, for a limited period, is discussed with maps. The data are chiefly instrumental. The paper deals mainly with shallow shocks, but new data on deep-focus shocks are included.

A revised table is given listing 54 great shocks from 1904 to 1939. All large shocks from 1926 to 1933 are listed, and epicenters are given for many others.

The earth's surface consists of relatively inactive blocks separated by active zones of three groups:

(1) The circum-Pacific zone includes a large majority of shallow shocks, a still larger fraction of shocks at intermediate depth, and all the very deep shocks. For shallow shocks the most active regions are Japan, the Aleutian arc, western Mexico, Melanesia, and the Philippines. In Japan the zone divides into an East Indian and a Polynesian branch, the latter following the andesite line. Three loops surround outlying areas of probably Pacific structure: the Caribbean loop, the loop of Suess's Southern Antilles (including South Georgia and the South Sandwich Islands), and a newly identified loop southwest of New Zealand, here called the Macquarie Island loop. A branch passes near the Galápagos group and follows the Easter Island Ridge, along a zone of suspected continental structure.

(2) The Mediterranean and trans-Asiatic zone includes the remainder of the large shallow shocks and of the intermediate shocks. The epicenters fall along structural trend lines.

(3) Narrow belts of shallow shocks extend (a) through the Arctic and Atlantic Oceans, following the Mid-Atlantic Ridge; (b) through the western Indian Ocean from Arabia into the Antarctic, probably connecting with the South Antillean loop; and (c) a similar but less active belt following the African rift valleys.

The Pacific basin (except in the Hawaiian Islands) and the continental

nuclear shields are nearly inactive. Between the stable shields and the active belts are areas of minor to moderate activity, with occasional large shocks.

Small shocks apparently occur everywhere. The relation of minor activity to the larger shocks is discussed, using southern California as an example.

The annual average includes about one great shock, about 100 potentially destructive shocks, and about one million shocks potentially strong enough to be felt in a settled area. Seismic energy is released at a mean rate of about 10^7 kilowatts; most of this is in the large shocks.

There is regular association, with notable regional exceptions, of earthquakes at various depths with volcanoes, gravity anomalies, and oceanic troughs or foredeeps. The several phenomena are frequently found in successive adjoining belts in a particular unilateral order. The persistance of oceanic troughs and gravity anomalies, together with the occurrence of earthquakes, requires that in these regions there is a continuously operating mechanism, such as would be provided by constant subcrustal flow.

WORKS TO WHICH REFERENCE IS MADE

Adams, C. E., Barnett, M. A. F., and Hayes, R. C. (1933) *Seismological report of the Hawke's Bay earthquake of 3rd February, 1931,* Dominion Observatory, Wellington, Bull. 85, 16 pages.

Arni, P. (1939) *Carte tectonique schematique de l'Anatolie et de son voisinage oriental,* Maden Tetkik ve Arama Enstitüsü Mecmuasi Üç Ayda Bir Çicar, Sene 4, Sayi: 2, p. 28.

Bastings, L. (1933) *Some seismological aspects of the Buller earthquake, 1929, June 16–17,* New Zealand Jour. Sci. Technol., vol. 15, p. 128–142.

——— (1935) *Destructive earthquakes in New Zealand, 1835–1934,* Dominion Observatory, Wellington, Bull. 103, p. 406–411.

Bellamy, E. F. (1936) *Index catalogue of epicentres for 1913–1930,* University Observatory, Oxford, 36 pages.

Berlage, H. P. (1940) *One hundred deep-focus earthquakes in the Netherlands Indies,* 6th Pacific Sci. Congr., Pr., vol. 1, p. 135–138.

Bobillier, Carlos (1933) *La sismicidad de Chile durante el año de 1931,* Universidad de Chile, Bol. del Servicio Sismol. no. 23, p. 6.

Boese, E., Villafaña, A., and García y García, J. (1908) *El temblor del 14 de abril de 1907,* Parerg. Inst. Geol. Mexico, II, p. 136–258.

Born, A. (1933) *Der geologische Aufbau der Erde,* Handbuch der Geophysik, vol. 2, p. 565–867, Berlin.

Bramhall, E. H. (1938) *The Central Alaska earthquake of July 22, 1937,* Seismol. Soc. Am., Bull., vol. 28, p. 71–75.

Branner, J. C. (1912) *Earthquakes in Brazil,* Seismol. Soc. Am., Bull., vol. 2, p. 105–117.

——— (1919) *Outlines of the geology of Brazil to accompany the geological map of Brazil,* Geol. Soc. Am., Bull., vol. 30, p. 189–337.

——— (1920) *Recent earthquakes in Brazil,* Seismol. Soc. Am., Bull., vol. 10, p. 90–114.

Brown, J. C., and Leicester, P. (1933) *The Pyu earthquakes of 3rd and 4th December, 1930, and subsequent Burma earthquakes up to January, 1932,* India Geol. Survey, Mem., vol. 62, p. 1–140.

Brunner, G. J. (1938) *The deep earthquake of May 26, 1932 near the Kermadec Islands,* Gerlands Beitr. z. Geophysik, vol. 53, p. 1–64.

Bryan, W. H., and Whitehouse, F. W. (1938) *The Gayndah earthquake of 1935,* Royal Soc. Queensland, Pr., vol. 49, p. 106–119.

Bucher, Walter H. (1940) *Submarine valleys and related geologic problems of the North Atlantic,* Geol. Soc. Am., Bull., vol. 51, p. 489–512.

Bullen, K. E. (1938) *On the epicentre of the 1934 Pahiatua earthquake,* Dominion Observatory, Wellington, Bull. 137, p. 61B–66B.

Byerly, Perry (1930) *The California earthquake of November 4, 1927,* Seismol. Soc. Am., Bull., vol. 20, p. 53–66.

——— (1935) *The first preliminary waves of the Nevada earthquake of December 20, 1932,* Seismol. Soc. Am., Bull., vol. 25, p. 62–80.

——— (1940) *Seismicity of the northern Pacific coast of the United States,* Geol. Soc. Am., Bull., vol. 51, p. 255–260.

Chubb, L. J. (1934) *The structure of the Pacific Basin*, Geol. Mag., vol. 71, p. 289–302.

Clapp, F. G. (1940) *Geology of eastern Iran*, Geol. Soc. Am., Bull., vol. 51, p. 1–102.

Cloos, Hans (1939) *Hebung—Spaltung—Vulkanismus*, Geologische Rundschau, vol. 30, p. 405–527.

Close, Upton, and McCormick, Elsie (1922) *Where the mountains walked*, Nat. Geogr. Mag., vol. 41, p. 445–464.

Conrad, V. (1932) *Die zeitliche Folge der Erdbeben und bebenauslösende Ursachen*, Handbuch der Geophysik, vol. 4, p. 1007–1185, Berlin.

Daly, R. (1940) *Strength and structure of the earth*, New York, 1940, 434 pages.

Dammann, Y. (1924) *Le tremblement de terre du Kan-Sou*, Bur. Centr. Sismologique Int., sér. B, monographies, fasc. 1, 92 pages.

Davison, Charles (1924) *A history of British earthquakes*, Cambridge, 416 pages.

——— (1931) *The Japanese earthquake of 1923*, London, 127 pages.

——— (1936) *Great earthquakes*, London, 286 pages.

——— (1938) *Studies on the periodicity of earthquakes*, London, 107 pages.

Doyle, Patrick (1882) *Note on an Indian earthquake*, Seismol. Soc. Japan, Tr., vol. 4, p. 78–83.

Dunn, J. A., Auden, A. M. N., and Wadia, D. N. (1939) *The Bihar-Nepal earthquake of 1934* (with seismometric study by S. C. Roy), India Geol. Survey, Mem., vol. 73, p. 1–391.

Du Toit, A. L. (1937) *Our wandering continents*, London, 366 pages.

Etzold, F. (1919) *Die sächsischen Erdbeben während der Jahre 1907–1915*, Sächsische Ges. d. Wiss., Leipzig, Abhandl., vol. 36, no. 3, p. 213–429.

Ewing, Maurice (1938) *Marine gravimetric methods and surveys*, Am. Philos. Soc., Pr., vol. 79, p. 47–70.

Farquharson, W. I. (1936) *Topography*, Brit. Mus. (Nat. Hist.), John Murray Expedition, Sci. Rept., vol. 1, no. 2.

Fisher, N. H. (1940) *The volcanoes of the mandated territory of New Guinea*, 6th Pacific Sci. Congr., Pr., vol. 2, p. 889–894.

Galitzin, B. (1911) *Das Erdbeben vom 3.–4. Januar 1911.* Acad. Imp. St. Pétersbourg, Bull., p. 127–136.

Gee, E. R. (1934) *The Dhubri earthquake of the 3rd July, 1930*, India Geol. Survey, Mem., vol. 65, p. 1–106.

Griggs, David (1939) *A theory of mountain-building*, Am. Jour. Sci., vol. 237, p. 611–650.

Gutenberg, Beno (1915) *Die mitteleuropäischen Beben vom 16. November 1911 und vom 20. Juli 1913*, Veröff. Zentralbureau Int. Seismol. Assoc., Strassburg, 84 pages, 32 plates.

——— (1925) *Bearbeitung von Aufzeichnungen einiger Weltbeben*, Senckenberg. Naturforsch. Ges., Abh., vol. 40, p. 57–88.

——— (1939) *Tsunamis and earthquakes*, Seismol. Soc. Am., Bull., vol. 29, p. 517–526.

——— (1941) *Changes in sea level, postglacial uplift, and mobility of the earth's interior*, Geol. Soc. Am., Bull., vol. 52, p. 721–772.

———, **and Richter, C.** (1934) *On seismic waves* (1st paper), Gerlands Beitr. z. Geophys., vol. 43, p. 56–133.

——— — ——— (1935) *On seismic waves* (2d paper), Gerlands Beitr. z. Geophys., vol. 45, p. 280–360.

——— — ——— (1936) *On seismic waves* (3d paper), Gerlands Beitr. z. Geophys., vol. 47, p. 73–131.

Gutenberg, Beno, and Richter, C. (1937) *Materials for the study of deep-focus earthquakes* (2d paper), Seismol. Soc. Am., Bull., vol. 27, p. 157–183.

——— — ——— (1938) *Depth and geographical distribution of deep-focus earthquakes,* Geol. Soc. Am., Bull., vol. 49, p. 249–288.

——— — ——— (1939a) *Depth and geographical distribution of deep-focus earthquakes,* (2d paper), Geol. Soc. Am., Bull., vol. 50, p. 1511–1528.

——— — ——— (1939b) *Evidence from deep-focus earthquakes. Structure of the crust. Continents and oceans,* in *Internal constitution of the earth,* p. 290–327, New York and London.

Hagiwara, T. (1940) *The Ogasima earthquake and its aftershocks,* Earthquake Res. Inst., Tokyo, Bull., vol. 18, p. 252–263.

Hayes, R. C. (1937) *The seismological aspects of the Wairoa earthquake of September, 1932,* Dominion Observatory, Wellington, Bull. 121, p. 858–865.

——— (1939) *The deep-focus earthquakes of the Southwest Pacific,* 6th Pacific Sci. Congr., Pr., vol. 1, p. 131–134.

Heck, N. H. (1938a) *The role of earthquakes and the seismic method in submarine geology,* Am. Philos. Soc., Pr., vol. 79, p. 97–108.

——— (1938b) *Earthquake history of the United States, part I,* U. S. Coast Geod. Survey, serial No. 609, 83 pages.

Heim, Arnold (1934) *Earthquake region of Taofu,* Geol. Soc. Am., Bull., vol. 45, p. 1035–1050.

Heiskanen, W. (1936) *Das Problem der Isostasie,* Handbuch der Geophysik, vol. 1, p. 878–951, Berlin.

Henderson, J. (1937) *The West Nelson earthquakes of 1929 (with notes on the geological structure of West Nelson),* Dept. Sci. Industr. Res., Bull. 55, Wellington, New Zealand, p. 65–144.

Hess, H. H. (1938) *Gravity anomalies and island arc structure with particular reference to the West Indies,* Am. Philos. Soc., Pr., vol. 79, p. 71–96.

Hodgson, E. A., and Doxsee, W. W. (1930) *The Grand Banks earthquake, November 18, 1929,* Eastern Sect. Seismol. Soc. Am., Pr. 1930 meeting, Washington, p. 72–79.

Hoffmeister, J. E. (1938) *The John Murray Expedition (1933–1934),* Geogr. Rev., vol. 28, p. 160–162.

Imamura, Akitune (1931) *Seismometric study of the recent destructive N. Idu earthquake,* Earthquake Res. Inst. Tokyo, Bull., vol. 9, p. 48–49.

——— (1937) *Theoretical and applied seismology,* Tokyo, 358 pages.

Ishimoto, M., *et al.* (1934) *Papers and reports on the tunami of 1933 on the Sanriku coast, Japan,* Earthquake Res. Inst. Tokyo, Bull., Suppl. vol. 1, Part 1, 271 pages and 226 plates; Part II, 250 pages.

Jeffreys, Harold (1923) *The Pamir earthquake of 1911 February 18, in relation to the depths of earthquake foci,* Royal Astron. Soc., Mo. Notices, Geophys. Suppl., vol. 1, p. 22–30.

Jenkins, Olaf P. (1938) *Geologic map of California,* Scale 1:500,000, 6 sheets, Div. Mines, Sacramento, California.

Jones, J C. (1915) *The Pleasant Valley, Nevada, earthquake of October 2, 1915,* Seismol. Soc. Am., Bull., vol. 5, p. 190–205.

Junner, N. R., *et al.* (1941) *The Accra earthquake of 22nd June, 1939,* Gold Coast Geol. Survey, Bull. 13, London, 67 pages, 6 plates, 2 maps.

Keith, Arthur (1930) *The Grand Banks earthquake,* Eastern Sect. Seismol. Soc. Am., Washington, Suppl. Pr. 1930 meeting, p. 1–5.

Kober, L. (1933) *Die Orogentheorie,* Berlin, 184 pages.

Koch, Lauge (1929) *The Geology of east Greenland. Stratigraphy of Greenland,* Meddelelser om Grønland, vol. 73, pt. 2, p. 1–320, København.

Kolderup, C. F. (1913) *Norges jordskjaelv*, Bergens Museums Aarbok 1913 nr. 8 (with summary in German), 151 pages.

Krige, L. J., and Venter, F. A. (1933) *The Zululand earthquake of the 31st December, 1932*, Geol. Soc. S. Africa, Tr., vol. 36, p. 101–112.

Kuenen, P. H. (1936) *The negative isostatic anomalies in the East Indies (with experiments)*, Leidsche Geolog. Mededeelingen, vol. 8, p. 169–214.

Kumagai, N. (1940) *Studies in the distribution of gravity anomalies in north-east Honsyu and the central part of the Nippon Trench, Japan*, Japan. Jour. Astron. Geophys., vol. 17, p. 477–551.

Kunitomi, S. I. (1931) *Notes on the North Idu earthquake of Nov. 26, 1930*, Geophys. Mag., vol. 4, p. 73–102, Tokyo.

——— (1937) *Preface*, Weather Bur. Tyôsen, Seismol. Bull. 1934, Zinsen, Tyôsen, Nippon.

Lawson, A. C., *et al.* (1908) *The California earthquake of April 18, 1906*, Carnegie Inst. Washington, 2 vols., atlas, 643 pages.

Lee, A. W. (1937) *On the travel of seismic waves from the Baffin Bay earthquake of November 20, 1933*, Meteorol. Office, Geophys. Mem., No. 74, London. 21 pages.

Lee, J. S. (1939) *Geology of China*, Thomas Murby and Co., London, 528 pages.

Lee, S. P. (1933) *Note on the earthquake of August 10, 1931*, Geol. Survey China, Seismol. Bull., Chiufeng seismic station, vol. 2, p. 51–60.

Lehmann, I. (1930) *P' as read from the records of the earthquake of June 16th 1929*, Gerlands Beitr. z. Geophysik, vol. 26, p. 402–412.

———, **and Plett, G.** (1932) *Untersuchung der europäischen Registrierungen der Erdbeben vom 18. VII. 1928, 24. X. 1930 und 13. XI. 1925*, Gerlands Beitr. z. Geophysik, vol. 36, p. 38–77.

Littlehales, G. W. (1932) *The configuration of the ocean basins*, in *Oceanography*, Nat. Res. Council, Bull. 85, p. 13–60. Washington, D. C.

Mace, C., and Bullard, E. C. (1939) *Gravity measurements in Cyprus*, Royal Astron. Soc., Mo. Notices, Geophys. Suppl., vol. 4, p. 473–480.

Macelwane, J. B. (1930) *The South Pacific earthquake of June 26, 1924*, Gerlands Beitr. z. Geophysik, vol. 28, p. 165–227.

Masó, M. S. (1918) *Great earthquake and tidal wave in southern Mindanao, P. I.*, Seismol. Soc. Am., Bull., vol. 8, p. 125–126.

——— (1924) *The Mati earthquake, April 14, 1924*, Weather Bur. Manila, Bull., reprint p. 1–2.

——— (1927a) *Ancient Philippine earthquakes, 1585–1865*, Weather Bur. Manila, Seismol. Bull., reprint p. 1–35.

——— (1927b) *Destructive and violent (VII–X R. F.) Philippine earthquakes and eruptions 1585–1925*, Weather Bur. Manila, Seismol. Bull., reprint p. 5–8.

Matuyama, Motonori (1936) *Gravity Survey by the Japanese Commission since 1932*, Intern. Union Geod., 6th Conf., Edinburgh, Report, 8 pages.

Matuzawa, Takeo (1935/1936) *Seismometrische Untersuchungen des Erdbebens vom 2. März 1933*, Earthquake Res. Inst. Tokyo, Bull., vol. 13, p. 171–193, 328–334; vol. 14, p. 38–67.

Meinesz, F. A. V. (1933) *Ergebnisse der Schwerebeobachtungen auf dem Meere in den Jahren 1923–1932*, Ergebnisse der Kosmischen Physik, vol. 2, p. 153–212.

——— (1939) *Review of gravity at sea*, Intern. Union Geod. Geophys., Commission on continental and oceanic structure, Adv. rept., p. 33–45. Washington, D. C.

——— (1940) *The earth's crust deformation in the East Indies*, Nederl. Akad. Pr., vol. 43, p. 278–293.

———, **Umbgrove, J. H. F., and Kuenen, Ph. H.** (1934) *Gravity expeditions at sea 1923–1932*, vol. 2, Netherlands Geod. Comm., Publ., Delft, 208 pages.

Middlemiss, C. S. (1910) *The Kangra earthquake of 4th April 1905*, India Geol. Survey, Mem., vol. 38, 409 pages and 28 plates.

Milne, J. (1905) *Preliminary notes on observations made with a horizontal pendulum in the Antarctic regions*, Royal Soc., Pr., vol. 76A, p. 284–295, London.

Minakami, Takeshi (1938) *The Hinomisaki-Oki earthquake of January 12, 1938*, Earthquake Res. Inst. Tokyo, Bull., vol. 16, p. 470–483.

Montessus de Ballore, F. de (1906) *Les tremblements de terre. Géographie Séismologique*, Paris. 476 pages.

Mushketov, D. (1935) *On seismicity of the Arctic*, Acad. Sci. U.S.S.R., Publ. Seismol. Inst., No. 61, p. 9–15.

——— (1936a) *Distribution and extent of seismotectonic zones in the Union of Soviet Socialist Republics*, Intern. Geol. Congr. 1933, Rep., vol. 2, p. 873–884, Washington, D. C.

——— (1936b) *Modern conceptions of the tectonics of Central Asia*, Intern. Geol. Congr. 1933, Rept., vol. 2, p. 885–894, Washington, D. C.

Nasu, Nobuji (1935) *The great Indian earthquake of January 15, 1934*, Earthquake Res. Inst. Tokyo, Bull., vol. 13, p. 417–432.

Obruchev, V. A., *et al.* (1928) *The earthquakes on the coast of the Black Sea in 1927 and the destiny of Crimea*, Library Govt. Botanical Garden, Nikita, Yalta, Crimea, U.S.S.R. (in Russian), 111 pages.

Oldham, R. D. (1923) *The earthquake of 7th August, 1895, in northern Italy*, Geol. Soc. London, Quart. Jour., vol. 79, p. 231–236.

Omori, F. (1907a) *Report on the great Indian earthquake of 1905*, Earthquake Investig. Comm. Publ. in Foreign Languages, no. 23, 16 pages, 22 plates; no. 24, 273 pages, Tokyo.

——— (1907b) *Preliminary note on the Formosa earthquake of March 17, 1906*, Imp. Earthquake Investig. Comm., Bull., vol. 1, p. 53–69, Tokyo.

——— (1923) *Note on the destructive Formosa earthquake of 1922*, Imp. Earthquake Investig. Comm., Seismol. Notes, no. 5, p. 9–16, Tokyo.

Ordoñez, Ezequiel (1931) *The Oaxaca earthquake*, Seismol. Soc. Am., Bull., vol. 21, p. 47–50.

Page, B. M. (1935) *Basin Range faulting of 1915 in Pleasant Valley, Nevada*, Jour. Geol., vol. 43, p. 690–707.

Poisson, Charles (1939) *Un cinquantenaire l'Observatoire d'Ambohidempona à Tananarive, Madagascar, 1889–1939*, p. 62–64 and 104–111, Paris.

Rajko, N., and Linden, N. (1935) *On the earthquake of 20. XI. 1933 in the Baffin Bay and on the distribution of epicentres in the Arctic*, Acad. Sciences U.S.S.R., Publ. Seismol. Inst., no. 61, p. 1–8.

Ramanathan, K. R., and Mukherji, S. M. (1938) *A seismological study of the Baluchistan (Quetta) earthquake of May 31, 1935*, India Geol. Survey, Rec., vol. 73, pt. 4, p. 483–513.

Reid, H. F., and Taber, Stephen (1919a) *The Porto Rico earthquakes of October–November, 1918*, Seismol. Soc. Am., Bull., vol. 9, p. 95–127.

——— ——— (1919b) *The Porto Rico earthquake of 1918 with description of earlier earthquakes*, U. S. House of Representatives, 66th Congr., 1st sess., doc. no. 269, 74 pages.

Repetti, W. C. (1931a) *Philippine earthquake epicenters south of Manila 1920–1929*, Weather Bur. Manila, Seismol. Bull. 1931 (Jan.–June), p. 37–50.

——— (1931b) *Philippine earthquake epicenters*, Weather Bur. Manila, Seismol. Bull. 1930 (July–Dec.), p. 71–85.

——— (1931c) *Philippine earthquakes, marine epicenters 1920–1929*, Manila Observatory, Publ., vol. 3, no. 9, p. 199–204.

Repetti, W. C. (1932) *Philippine earthquake epicenters (1920 to 1929) south of Manila*, Weather Bur. Manila, Seismol. Bull. 1931 (July–Dec.), p. 37–52.

——— (1935) *Tectonic lines of the Philippine Islands*, Weather Bur. Manila, Seismol. Bull. 1934 (July–Dec.), p. 57–71.

——— (1939) *Catalogue of earthquakes felt in Guam 1825–1938*, Weather Bur. Manila, Seismol. Bull. 1939 (Jan.–June), p. 27–43.

——— (1940) *Philippine earthquake epicenters 1930–1932*, Weather Bur. Manila, Seismol. Bull. 1939 (July–Dec.), p. 65–77.

Richter, C. F. (1935) *An instrumental earthquake magnitude scale*, Seismol. Soc. Am., Bull., vol. 25, p. 1–32.

——— (1936) *Earthquake magnitudes and statistics*, Seismol. Soc. Am., meeting April 1936 (not printed).

——— (1940) *Earthquake epicenters and structure of the Pacific region of north America (southern part)*, 6th Pacific Sci. Congr., Pr., vol. 1, p. 113–118.

Roos, S. E. (1937) *The submarine topography of the Ross Sea and adjacent waters*, Geogr. Rev., vol. 27, p. 574–583.

Rosenthal, Elmar (1906) *Les tremblements de terre du Kamtchatka en 1904*, Bureau Central de l'Association Internationale de Sismologie, Publ., Strassburg, p. 31–52.

——— (1907) *Katalog der im Jahre 1904 registrierten seismischen Störungen*, Bureau Central de l'Association Internationale de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 145 pages.

Rudolph, E. (1887) *Ueber submarine Erdbeben und Eruptionen*, Gerlands Beitr. z. Geophysik, vol. 1, p. 133–373.

——— (1895) *Ueber submarine Erdbeben und Vulkane (Zweiter Beitrag)*, Gerlands Beitr. z. Geophysik, vol. 2, p. 537–666.

———, **and Szirtes, S.** (1912) *Das kolumbianische Erdbeben am 31. Januar 1906*, Gerlands Beitr. z. Geophysik, vol. 11, p. 132–190 and 207–275.

———, **and Tams, E.** (1907) *Seismogramme des nordpazifischen und südamerikanischen Erdbebens am 16. August 1906, Begleitworte und Erläuterungen*, Zentralbureau und Hauptstation für Erdbebenforschung, Strassburg i. E, 98 pages and 58 plates.

Salomon-Calvi, W. (1940) *Les tremblements de terre d'Erzincan du 21. XI. et du 27. XII. 1939*, Maden Tetkik ve Arama, Sene 5, Sayi 1/18, p. 27–30.

Scherer, J. (1912) *Great earthquakes in the island of Haiti*, Seismol. Soc. Am., Bull., vol. 2, p. 161–180.

Sieberg, A. (1910) *Die Erdbebentätigkeit in Deutsch-Neuguinea (Kaiser-Wilhelmsland und Bismarckarchipel)*, Petermanns Geographische Mitt., II, Heft 2/3.

——— (1920) *Mitteilungen über Erdbeben im Jahre 1912*, Hauptstation für Erdbebenforschung, Jena, 26 pages.

——— (1932a) *Erdbebengeographie*, Handbuch der Geophysik, vol. 4, p. 687–1005, Berlin.

——— (1932b) *Untersuchungen über Erdbeben und Bruchschollenbau im östlichen Mittelmeergebiet*, Medizinisch-Naturwiss. Ges. zu Jena, Denkschriften, vol. 18, 2. Lieferung, p. 161–273.

——— (1940) *Beiträge zum Erdbebenkatalog Deutschlands für die Jahre 58 bis 1799*, Deutscher Reichs-Erdbebendienst, Mitt., Heft 2, Reichsanstalt f. Erdbebenforschung, Jena.

Sommer, Henrietta (1931) *On the question of dispersion in the first preliminary seismic waves*, Seismol. Soc. Am., Bull., vol. 21, p. 87–185.

Stille, H. (1924) *Grundfragen der vergleichenden Tektonik*, Berlin, 443 pages.

——— (1936) *Tektonische Beziehungen zwischen Nordamerika und Europa*, Internt. Geol. Congr., 1933, Rep., vol. 2, p. 829–838.

Szirtes, Siegmund (1909) *Katalog der im Jahre 1905 registrierten seismischen Störungen, II. Teil*, Bur. Central Int. de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 68 pages.

——— (1910) *Katalog der im Jahre 1906 registrierten seismischen Störungen, II. Teil*, Bur. Central Int. de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 85 pages.

——— (1912) *Registrierungen der besser ausgeprägten seismischen Störungen des Jahres 1907*, Bur. Central Int. de Sismologie, Publ., Strassburg, 111 pages.

Taber, Stephen (1920) *Jamaica earthquakes and the Bartlett trough*, Seismol. Soc. Am., Bull., vol. 10, p. 55–89.

——— (1922) *The seismic belt in the Greater Antilles*, Seismol. Soc. Am., Bull., vol. 12, p. 199-219.

Tams, E. (1922) *Die seismischen Verhältnisse des europäischen Nordmeeres*, Centralblatt f. Mineralogie, Geologie und Palaeontologie, Jahrg. 1922, No. 13, p. 385–397.

——— (1927a) *Die seismischen Verhältnisse des offenen Atlantischen Oceans*, Zeitschr. f. Geophysik, vol. 3, p. 361–363.

——— (1927b) *Erdbeben im Gebiet der Nordenskiöld See*, Gerlands Beitr. z. Geophysik, vol. 17, p. 325–331.

——— (1928) *Die seismischen Verhältnisse des offenen Atlantischen Oceans*, Gerlands Beitr. z. Geophysik, vol. 18, p. 319–353.

——— (1930a) *Die Seismizität des Südantillenbogens*, Zeitschr. f. Geophysik, vol. 6, p. 361–369.

——— (1930b) *Das Epicentrum des südatlantischen Grossbebens vom 27. Juni 1929*, Zeitschr. f. Geophysik, vol. 6, p. 480–482.

——— (1931) *Die Seismizität der Erde*, Handbuch der Experimentalphysik, vol. 25, part 2, p. 361–437.

Tarr, R. S., and Martin, L. (1912) *The earthquakes at Yakutat Bay, Alaska*, U. S. Geol. Survey, Prof. Paper 69.

Townley, S. D. (1931) *The New Zealand earthquake of February 3, 1931*, Seismol. Soc. Am., Bull., vol. 21, p. 251-260.

———, **and Allen, M. W.** (1939) *Descriptive catalog of earthquakes of the Pacific Coast of the United States 1769 to 1928*, Seismol. Soc. Am., vol. 29, p. 1–297.

Tsuboi, C. (1939) *Discussion on deep focus earthquakes*, 6th Pacific Sci. Cong., Pr. (not published).

——— (1940) *Isostasy and maximum earthquake energy*, Tokyo Imp. Acad., Pr., vol. 16, p. 449–454.

Turner, H. H. (1917) *The large earthquakes of 1913*, Brit. Assoc. Seismol. Comm., 74 pages.

———, *et al.* (1923–1940) *International Seismological Summary for 1918–March 1934*, Univ. Observatory, Oxford.

Vaughan, T. W., *et al.* (1940) *Report of the Committee on the criteria and nomenclature of the major divisions of the ocean bottom*, Assoc. Océanogr. Phys., Publ. Sci., No. 8, 124 pages.

Visser, S. W. (1934) *Determination from world records of the zero time and the epicentre of the Pegu earthquake of May 5th, 1930*, India Geol. Survey Rec., vol. 65, pt. 2, p. 271–278.

Wadati, K. (1931) *Shallow and deep earthquakes* (3d paper), Geophys. Mag., vol. 4, p. 231–283, Tokyo.

——— (1940) *On deep-focus earthquakes in Japan and vicinity*, 6th. Pacific Sci. Congr. Pr., vol. 1, p. 139–147.

Wanner, E. (1934) *Erdbebenkatalog der Schweiz für die Jahre 1856–1879* (with map *Erdbebenzentren der Schweiz 1856–1933*), Schweiz. Meteorologische Zentral-anstalt, Jahresbericht des Erdbebendienstes, p. 16–23, Zürich.

——— (1937) *Zur Statistik der Erdbeben*, Gerlands Beitr. z. Geophysik, vol. 50, p. 85-99 and 223-228.

Weiss-Xenofontova, Z., and Popoff, V. (1940) *Sur les tremblements de terre à la centrale région de l'Oural*, Acad. Sci. U.S.S.R., Publ. Seismol. Inst., No. 104, p. 1–12 (in Russian).

West, W. D. (1934) *The Baluchistan earthquakes of August 25th and 27th, 1931*, India Geol. Survey, Mem., vol. 67, pt. 1, 82 pages.

——— (1935) *Preliminary geological report on the Baluchistan (Quetta) earthquake of May 31st, 1935*, India Geol. Survey, Rec., vol. 69, p. 203–241.

——— (1936) *Geological account of the Quetta earthquake*, Min. Geol. Inst. India, Tr., vol. 30, p. 138–142.

Willis, Bailey (1923) *A fault map of California*, Seismol. Soc. Am., Bull., vol. 13, p. 1–12.

——— (1928) *Earthquakes in the Holy Land*, Seismol. Soc. Am., Bull., vol. 18, p. 73-103.

——— (1929) *Earthquake conditions in Chile*, Carnegie Inst. Washington, Publ. 382, 176 pages and 75 plates.

——— (1933) *Earthquakes in the Holy Land—a correction*, Seismol. Soc. Am., Bull., vol. 23, p. 88–89.

——— (1937) *Geologic observations in the Philippine Archipelago*, Nat. Res. Council Philippine Islands, Bull. 13, 127 pages.

——— (1939) *Wrinkles of Asia*, Sci. Mo., vol. 49, p. 431–451.

——— (1940) *Philippine Archipelago, an illustration of continental growth*, 6th Pacific Sci. Congr., Pro., vol. 1, p. 185–200.

Wilser, J. L. (1928) *Der südrussische Tafelrand in Vorder- und Mittelasien*, Neues Jahrbuch f. Mineralogie . . . . , Beilageband 51, Abt. B, p. 151–184.

Wood, H. E. (1913) *On the occurrence of earthquakes in South Africa*, Seismol. Soc. Am., Bull., vol. 3, p. 113–120.

Wood, H. O. (1914) *On the earthquakes of 1868 in Hawaii*, Seismol. Soc. Am., Bull., vol. 4, p. 171–203.

——— (1933) *Volcanic earthquakes*, in *Physics of the earth*, vol. 6, *Seismology*, Nat. Res. Council, Bull. 90, p. 9-31, Washington, D. C.

Wüst, Georg (1934) *Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans*, Die Naturwissenschaften, vol. 22, p. 241–244.

——— (1939a) *Die Grossgliederung des atlantischen Tiefseebodens*, Geol. Rundschau, vol. 30, p. 132–137.

——— (1939b) *Das submarine Relief bei den Azoren*, Preuss. Akad., Abh., Jahrg. 1939, Phys.-Math. Klasse, Nr. 5, p. 46–58.

——— (1939c) *Bodentemperatur und Bodenstrom in der atlantischen, indischen und pazifischen Tiefsee*, Gerlands Beitr. z. Geophysik, vol. 54, p. 1–8.

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